An economic comparison of forest recreation, timber and carbon fixing values with agriculture in Wales: a geographical information systems approach

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ABSTRACT

The research examines the financial and economic viability of transferring land presently under agricultural use into multipurpose farm-forestry in Wales. Three woodland benefit streams are examined in detail: the value of open-access recreation; the production of timber and; the net carbon storage generated by afforestation. Modelling of the spatial variability determining the production of these benefits is enhanced by the novel application of a geographical information system (GIS). Monetary evaluation of non-market recreation benefits is achieved by reference to both the contingent valuation and travel cost methods with prior studies being reviewed and new work presented. By contrast carbon storage benefits are valued purely by reference to the existing literature. Both of these analyses yield social values whereas our study of timber production produces both shadow and market valuations.

Our GIS-based methodology is also applied to the modelling of agricultural values for the two major farm sectors (mainly sheep and mainly milk production) of the study area. Again both social and financial values are calculated.

By comparison of the various values estimated across the above analyses we estimate both the financial and social values associated with potential transfers of land from conventional agriculture into farm-forestry. The financial values generated by our analysis support the present low levels of conversion out of agriculture. However, the social values estimated suggest that the present situation constitutes a significant market failure, particularly in the mainly sheep farming sector where cost benefit analysis suggests that substantial net social benefits could be generated through conversions into multi-purpose woodland.

THANKS AND ACKNOWLEDGMENTS

This research took about seven years to complete during which time I changed careers twice, jobs four times, lived in four counties in eight houses (not simultaneously) three of which I bought (two of which I eventually and with great relief sold), met the woman of my dreams, married her and had three wonderful children (at the last count). Life has therefore been "eventful" during this period and no doubt this thesis would have been finished a lot sooner had it been otherwise. I thank God (literally) that this was not the case.

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Chapter 1: Introduction

1.1 THESIS

Perhaps the most often quoted definition of an economist is of someone who knows the price of everything and the value of nothing[1]. Such a description is sadly true of most of the discipline. However (if I may briefly stray away from that third person who seems the obligatory, impersonal author of all modern academic papers[2]), to me it is an awareness of the distinction between value and price which separates out the true economist from the glorified book-keepers and accountants who so often masquerade under such a title. Recent years have seen a proliferation of badge-engineering in which so-called new disciplines such as environmental or ecological economics have risen to prominence. However, whilst these are appealing titles, in essence they represent not a radical departure but rather a very welcome return to the basic principles and domain of economics - the analysis of true value.

1.1.1 THE NATURE OF VALUE

It is one of these basic principles which underpins this study: namely the assumption that values can be measured by the preferences of individuals.[3] The interaction of preferences with the various services provided by a commodity generates a variety of values. Many economists have studied the nature of these values, however, a useful starting point is the concept of aggregate or total economic value (TEV) (Pearce and Turner, 1990; Bateman, 1991a; Bateman and Turner, 1993; Turner *et al.*, 1994; Bateman, 1995a/b; Turner, forthcoming).

Figure 1.1 shows how TEV can be broken down into its constituent parts and illustrates these with reference to certain of the values generated by the principal commodity under consideration in this study; woodland.

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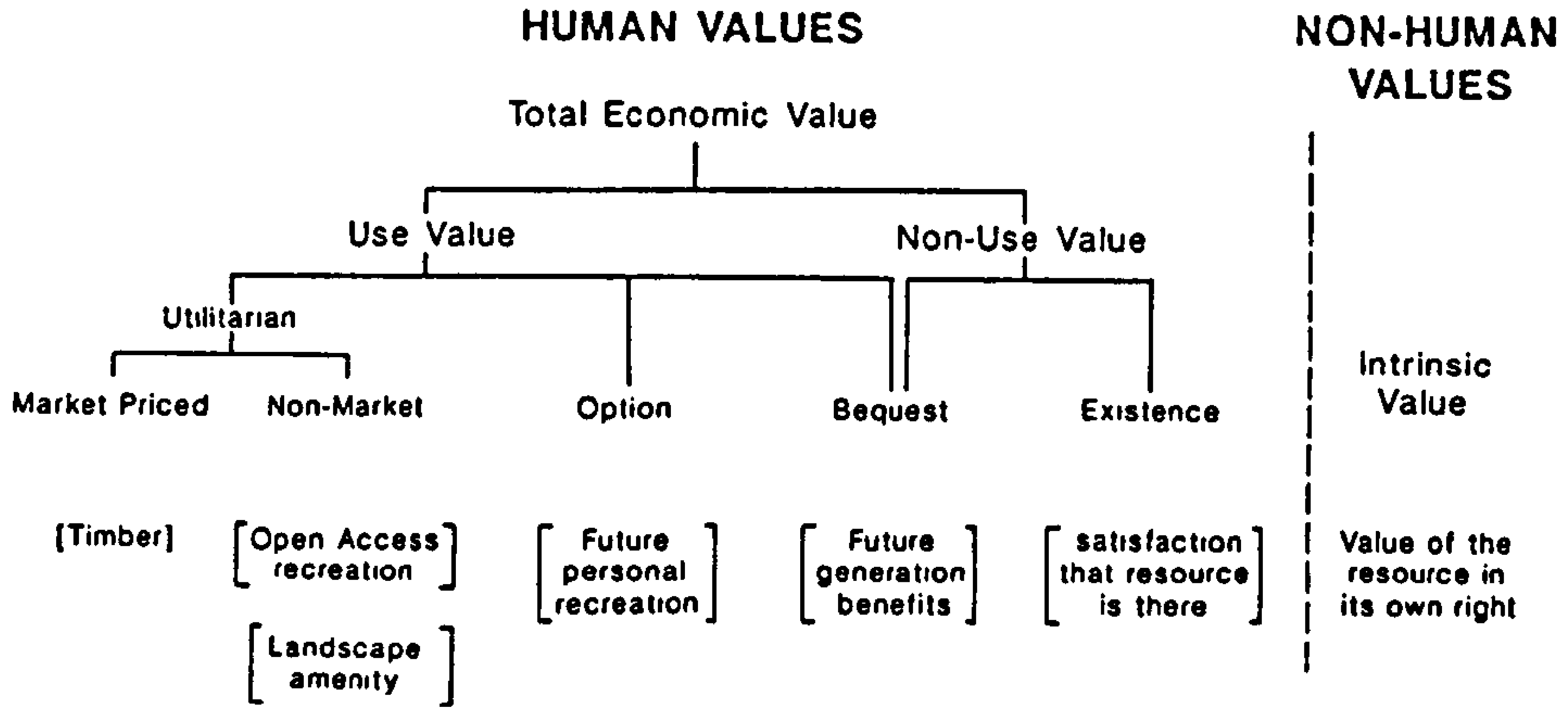
[1]This derives from a corruption of Oscar Wilde's definition of a cynic in *Lady Windermere's Fan* (Act III). However, given the perceived similarity between the two groups it is easy to see how such a confusion may have arisen. (With thanks to Olvar Bergland, Colin Price and others regarding this.)

[2]It was not always so. In reading the papers of one of our most eminent economists (and I use the term most correctly) John Hicks, the reader is addressed by a real person who talks directly, plainly and with a clarity of expression which sadly dear reader I do not possess (as you will soon discover).

[3]Speculations upon this issue and in particular about whether individuals have definite preferences are presented by Sugden (forthcoming).

Figure 1.1: The total economic value of woodland



Source: Adapted from Bateman (1995a)

The bulk of economic analyses concentrate upon the instrumental or use values of a commodity. Most prominent amongst these are the direct use values generated by private and quasi-private goods (Bateman and Turner, 1993) which are often partly reflected by market prices, and those indirect use values associated with pure and quasi-public goods (ibid) which generally have no market price description. A unifying characteristic of these values is that they are all generated by the present use of the commodity by the valuing individual. An extension of the temporal frame allows for the possibility of individuals valuing the option of future use (Weisbrod, 1964; Cicchetti and Freeman, 1971; Krutilla and Fisher, 1975; Kriström, 1990). Related to this is the notion of bequest value wherein the valuing individual gains utility from the provision of use or non-use values for present and/or future others. Pure non-use values are mostly commonly identified with the notion of valuing the continued existence of entities such as certain species of flora and fauna or even whole ecosystems. As before this is generally both an intra- and inter-generational value and because of the lack of an instrumental element has proved problematic to measure. Nevertheless, the theoretical case for the 'existence of existence value' is widely supported (e.g. Young, 1992).

Wider definitions of value have been argued for. An important issue concerns the extent of the 'moral reference class' (Turner *et al.*, 1994) for decision making. One question here arises from the treatment of other (both present elsewhere and future) humans while another concerns whether animal, plant and ecosystem interests should be placed on an equal footing with human preferences. The modern origins of such a view can be traced to Goodpastor (1979) and Watson (1979) who take the Kantian notion of universal laws of respect for other persons and extend this to apply to non-human others. Watson feels that those higher-animals such as chimpanzees (which he argues are capable of reciprocal behaviour) should be accorded equal rights with humans. Hunt (in Perman *et al.*, 1996) and Rollston (1988) build upon the land ethic of Leopold (1949) to extend this definition of moral reference even further to include all extant entities, an approach which Singer (1993) defines as the 'deep ecology' ethic. Such a paradigm argues that these entities possess an 'intrinsic' value separate from anthropocentric existence values. A further departure from conventional utilitarianism is proposed by Turner (1992 and forthcoming) who argues that all the elements of TEV can be seen as secondary to a primary environmental quality value which is a necessary prerequisite for the generation of all subsequent values. Sidestepping the theoretical case for such philosophical extensions, a practical problem with these non-TEV values is that they are essentially beyond the scope of conventional, anthropocentric, preference-based economic valuation. Given that in this study we constrain the moral reference class to present humans alone, this in turn defines TEV as the appropriate extent of value definition. However, this still leaves the problem of how such values should be measured.

1.1.2 FROM VALUES TO APPRAISALS: DIFFERING PARADIGMS

One solution to the problem of valuation might be to abandon conventional neoclassical economic analysis in favour of modified or alternative appraisal and decision making strategies. One such alternative is to base decisions upon expert judgement and restrict the role of economics to the identification of least cost methods for achieving stated aims (see, for example, OECD, 1991). Such a cost-effectiveness approach may be optimal for a risk averse society faced with high risk, high uncertainty problems such as the treatment of persistent pollutants (Opschoor and Pearce, 1991). Here a useful decision guide is provided by the precautionary principle advocated by 'ecological economics' (see, for example, Costanza and Daly, 1992; Toman, 1992; Turner *et al.*, 1995).

However, in situations where the precautionary principle does not apply (particularly for low risk, low uncertainty decisions) then a cost-effectiveness approach may entail avoidable and, in some cases, major net welfare losses compared to a solution based upon cost-benefit analysis (CBA). Such a position is adopted by those who argue for an 'environmental economics' paradigm (see, for example, Pearce *et al.*, 1989; Department of the Environment, 1993; Pearce, 1996). Here supporters accept preference based values as the basis of decision making but argue for full assessment of TEV as opposed to the concentration upon market based measures which appears to dominate much present practical decision making.

This choice between ecological and environmental economics can be characterised as one between principle or pragmatism. The argument for an ecological economics approach is that nothing less will preserve the environmental integrity which is vital if the present 'cowboy economy' (Boulding, 1966) is to attain a state of sustainable development. The environmental economic critique is that such a rigid approach fails to recognise the mechanisms through which present day decision making operates and thereby risks being ignored. In the absence of hindsight it is impossible to know which strategy is most likely to influence the presently unsustainable course of economic growth.

Our own position is that the two paradigms need not be in conflict and that a modified precautionary principle can be used to assess which approach is appropriate for any given decision situation. Furthermore, we see a role for public preferences within this process. For cases where expert assessment and/or informed public opinion identifies high potential risks or uncertainties from a given strategy or decision then a precautionary, ecological economics approach would appear justifiable. In instances where this is not the case then an environmental economics analysis seems likely to be optimal. Both are significantly superior to simple market-based appraisals.

1.2 THEORETICAL, METHODOLOGICAL AND EMPIRICAL BASIS OF THE STUDY

We therefore need to select the appraisal paradigm which is most appropriate for the subject under analysis. This thesis examines the economic potential for conversions of land use from conventional agriculture into woodland in Wales. Two points are immediately important here. First we are interested in the full range of economic values generated by such a change in land use. Second, following initial review (Bateman, 1991a and b, 1992), it became apparent that large scale unquantifiable risks or uncertainties were not a major factor in such an analysis. Given this, the adoption of an environmental economic CBA paradigm seemed defensible.

CBA is, in effect, an appraisal of the social worth of a project and the study presented in this thesis attempts to move beyond simple market related assessments of value to a more complete analysis of TEV. In assessing woodlands we attempt to be comprehensive although in practice focus falls upon timber production, open-access informal recreation, and the value of carbon sequestration (i.e. global warming abatement). This is compared to an appraisal of the social value of agriculture which takes account of items such as the subsidy transfers currently paid by society to farmers. However, while such an economic analysis is of use in informing decision makers and shaping optimal policy change, it cannot of itself predict farmers response to that change unless the impact upon farm incomes are also known. Consequently the study also examines farm gate incomes under present and potential future policy scenarios.

The ultimate objective of this study is therefore to provide a policy analysis tool. However, whilst the theoretical CBA framework of the research is conventional, the extent of application and the methodology employed is innovative. The depth of analysis is, we feel, more rigorous than in previous studies. Furthermore, the methods developed involve a spatial analytic framework which, to our knowledge, is unique.

Regarding this latter point we make extensive use of geographical information systems (GIS) throughout this study. A GIS is a software package capable of holding, interrogating and manipulating spatially referenced data such as digital maps. Through this facility we can combine environmental and other spatial data with more conventional variables into the stochastic economic models which underpin this study. As we demonstrate through the contexts of modelling timber yield, carbon sequestration, recreational demand and agricultural productivity, the ability to integrate diverse datasets yields a substantial improvement in the modelling of such variables and their consequent values. However, equally important is the superior display and interrogation of resultant models permitting the decision maker to readily comprehend the impact of alternative policy choices. It is this dual capability of improved modelling and display which we feel establishes the potential of a GIS for significantly improving economic modelling.

1.2.1 THE COST AND BENEFITS OF WOODLAND: LIMITATIONS OF THE STUDY

Figure 1.2 illustrates the complexity of internal and external costs and benefits which are generated by woodland. Here the internal costs and benefits are shown in shaded boxes. These items all have market prices from which shadow values may be derived. Certain external items also have related market prices from which values may again be estimated; these are shown in the broken line boxes in figure 1.2. However, the remaining externalities do not have related market prices thereby making valuation problematic.

Our study sets out to provide a full environmental economic assessment of all the values associated with the proposed conversion of agricultural land use into woodland. However, we have to recognise certain limitations to this study. First, methods for the monetary evaluation of preferences for non-market goods and services are not uniformly developed for all value types. In particular, methods for the evaluation of non-use benefits such as existence values have been the subject of sustained criticism in recent years (see Chapter 2). Our study reflects these reservations by concentrating upon use-values. Secondly, time constraints and data availability problems meant that even our treatment of all use values is somewhat uneven. Thirdly, we are only considering a conversion from agricultural land to woodland and not any other alternative use. Strictly speaking this contravenes the principles of CBA which state that the appraisal of opportunity costs should include the assessment of a wide range of feasible alternative resource uses (Pearce, 1983; Bateman *et al.*, 1993). A fourth issue is that of equity and its root: ethics.

1.2.1.1. A note on ethics[4]

Ethics and economics have often be presented as strange bedfellows. Indeed many proponents of the 'positive economics' which has dominated so much of twentieth century economic analysis argue that the two concepts cannot be related "in any form but mere juxtaposition" (Robbins, 1935: p.148). However, this has not always been a widely held

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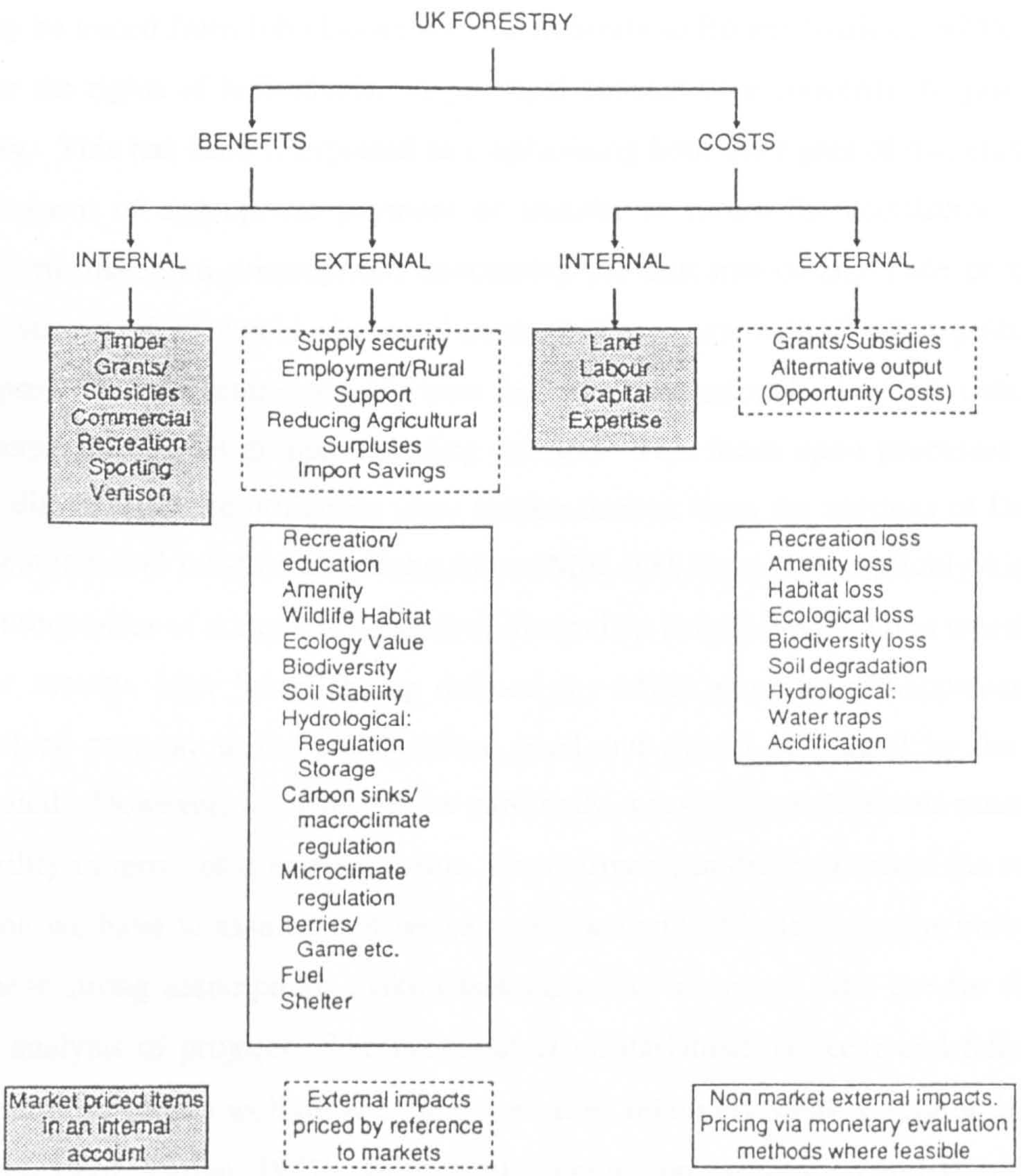
[4]This discussion relies heavily on Perman *et al.* (1996), Kneese and Schulze (1985) and Pearce and Turner (1990). Relevant discussions are also presented in Beauchamp and Bowie (1988) and Sen (1987).

Figure 1.2: Costs and benefits of woodland



Notes:

1. Here 'internal' refers to forest operator costs and benefits whether Private Woodland or Forestry Commission. 'External' refers to costs and benefits accruing directly to society.
2. Shadow pricing techniques must be applied to all values.
3. Not all the items listed may be valid (eg. import substitution argument).

Source: Bateman (1992)

belief. Indeed the early great economists were explicitly concerned with morality and ethics.[5,6]

Two ethical positions which have had a major impact upon the development of economic thought are the libertarian and utilitarian schools of thought. The libertarian view, which may be traced from John Locke and Adam Smith to Robert Nozick (1974), emphasises respect for the rights of individuals. A principal concept here concerns the just acquisition of property. This has been interpreted as emphasising both the rights of ownership and also the requirement of appropriate payment or transfer in return for acquisition. However, libertarianism makes no prescriptions concerning the outcome of any trade or transfer. In particular such a view would almost always condemn any redistributive policy, whether between present or to future people (intra and intergenerational transfers) unless they are freely entered into by all groups including donors.[7] This focus upon processes rather than outcomes differs from the utilitarian view (which derives from the writings of David Hume, Jeremy Bentham and most notably John Stuart Mill (1863)), which explicitly highlights the ethical consequences of actions. Classical utilitarianism judges actions upon whether they are 'good' for society, with 'good' being defined (by Mill) in terms of happiness or utility. Actions which promote utility are therefore good and should be judged by the amount of utility created. However, for utility to be cardinally measurable individuals must be able to express utility in terms of a numeric value. Furthermore, in order to assess the social utility of an action we have to assume that we can compare and add utility across individuals.

These strong assumptions make Classical utilitarianism of little use for the practical economic analysis of projects. The neoclassical utilitarianism (Kneese and Schulze, 1985) which underpins modern welfare economics requires relatively weaker assumptions (Layard and Walters, 1978; Varian, 1987). In particular a common assumption underpinning CBA is that the marginal utility of consumption is equal across all individuals. If this is so we can ignore distributive issues (which are vital under Classical analysis) as any action which creates net benefits unambiguously raise social welfare. However, in reality such an assumption seems unlikely to hold, prompting some CBA analysts to explicitly consider the

[5]Interestingly Adam Smith's post at the University of Glasgow was as Professor of Moral Philosophy.
[6]Reviews of the work of Marx, Marshall, Pareto, Keynes and others are presented in Schumpeter (1952).
[7]This would conventionally rule out any governmental action towards the enforced provision of such transfers.

equity implications of their analyses (e.g. Squire and van der Tak, 1975). For many years such commentators were a generally inconspicuous minority within the profession of economics. However, since the 1960's concerns regarding the effects of environmental degradation upon present and future generation, and the issue of North/South inequality have meant that discussions concerning the ethical basis of economics have grown. These concerns regarding the need to consider equity as well as economic efficiency have recently coalesced within what has been termed the Sustainable Development (SD) debate (WCED, 1987; Pearce *et al.*, 1990).

Both intra- and inter-generational equity issues are central to the SD debate which has in essence proposed an alternative to utilitarianism as a new ethical basis for economics. Pivotal to this has been the work of Page (1977) and in particular Rawls (1972). Rawls' Theory of Justice can in fact be seen as a direct development of Kants universal laws. Here the individual enjoys common liberties compatible with equal rights for others, while valid inequalities only result from personal attributes which are accessible to all (e.g. work and learning as opposed to sex and creed). This latter prescription has important consequences for equity as Rawls argues that under such a system the optimal allocation of resources is one that is made behind a 'veil of ignorance' as to their intra- and intergenerational incidence. This can be seen as being in direct conflict with the individual maximisation principle of utilitarianism.[8] This is perhaps most clearly demonstrated in the recent literature regarding sustainability. Turner and Pearce (1993) identify four alternative positions ranging from 'very weak' to 'very strong sustainability'. Each definition moves further from a conventional Utilitarian to a Rawlsian position on equity, steadily imposing more constraints upon resource use (most notably natural capital).

The ethical position adopted in this study

As discussed above there are a number of ethical positions which could be adopted for this study. Despite our own sympathy with the Rawlsian/Strong Sustainability view, our

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[8]The economic implications of Classical and Neo Classical Utilitarian and Rawlsian ethical positions can be expressed through consequent social welfare functions (SWF). Classical Utilitarianism implies an additive SWF of the form: $W = \beta_1 I^A + \beta_2 U^B$ where W = social welfare; U^A, U^B = the total utility enjoyed by individuals A and B respectively; β_1, β_2 = weights used to calculate W. Neo Classical Utilitarianism relaxes the assumption of additivity such that $W = W(U^A, U^B)$. Finally, following Solow (1974), the Rawlsian position can be expressed as the maxi-min function in which we maximise $W = \min(U^A, U^B)$. Note that Perman *et al.* (1996) suggest that Rawls may have strongly objected to the latter utilitarian reformulation of his work.

self-assessment is that the study is essentially neoclassically utilitarian in its ethical basis. The definition of values inherent in the TEV concept remains anthropocentric and is therefore consistent with the extended utilitarian view discussed by Perman *et al.* (1996). The most non-Rawlsian characteristic of this study is the absence of an explicit incorporation of any precautionary principle or equity constraint. Some commentators may argue that the sensitivity analysis across various discount rates (discussed in chapter 6) which we apply to our CBA effectively addresses the issue of intergenerational equity. However, as Hanley and Spash (1993) highlight, such an approach will not ensure equality of wellbeing across generations. Similarly we do not include explicit considerations of distributional effects nor do we include any analysis which could be construed as compatible with a Rawlsian maxi-min criteria. Our approach therefore is, in theoretical terms (and in terms of the ethical basis of that theory), essentially conventional. It is only in the practice of this analysis that we have attempted to improve upon convention.

This theoretical standpoint should not be taken as implying a wholesale rejection of the Rawlsian or strong sustainability positions. Rather it is a pragmatic extension of accepted decision-analysis practice.

1.2.2 SELECTION OF THE CASE STUDY AREA

While the fundamental objective of this study was the comparison of woodland with agricultural values, a supplementary initial goal was to see how this comparison varied spatially over a diversity of sites. Accordingly an initial research framework envisioned three case studies at two sites in England (one stretching from the Exe Valley across Dartmoor and the other located in North Norfolk) and one in Wales (a 10km wide transect running from Aberystwyth to Newtown). These sites were chosen to reflect a diversity of environments ranging from lowland areas yielding high agricultural productivity, to extreme upland locations where only marginal farming activities are feasible.

However, in the event it proved impossible to obtain a full set of the data necessary to model the diversity of woodland and agricultural values associated with these three areas. Specifically the Ministry of Agriculture, Fisheries and Food (MAFF) refused to release the farm level agricultural data for England which we felt was necessary to exploit the spatial analytic capabilities afforded by a GIS.[9] Accordingly attention was turned exclusively to Wales where the relevant authorities were highly supportive of our work (for which we are very grateful). However, to compensate for the lack of English data it was decided to expand the Welsh study area to encompass the entire principality, thereby including high productivity lowland as well as upland areas.[10]

1.2.2.1 Data sources

This research has drawn upon a variety of data from a number of sources. All data was provided free or for a reasonable handling charge. We are very, very grateful to a number of people for this cooperation without which the research could not have been undertaken.

Data on farm level agricultural activities, costs and revenues was obtained from the Farm Business Survey in Wales (FBSW). We are indebted to the enlightened attitude of the FBSW who, by being prepared to enter into a confidentiality agreement whereby no farm level results were reported, facilitated a highly substantial improvement in the ability to model agricultural production and its value by allowing us to link farm level decisionmaking to the local environment through the grid reference coordinates of the farm.

Environmental data was provided in the form of the LandIS database kindly loaned by the Soil Survey and Land Research Centre (SSLRC), Cranfield. This is the premier repository of land information data for England and Wales. When used in conjunction with the FBSW data this provided the highest quality combination of information possible for modelling agriculture in the study area.

This high quality was maintained in our final principal data source; the Forestry Commission's (FC) Sub-Compartment Data Base (SCDB). This is the most extensive and comprehensive source of woodland data in the UK and is again spatially referenced to a high degree of accuracy permitting synthesis with the environmental data contained in the LandIS database.

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[9] The only data proffered was the Parish Census database. This both fails to identify individual farm locations (thus rendering accurate production modelling unfeasible) and does not report certain key profitability variables.

[10] Nevertheless, given the relatively low population density of Wales we do regret not being able to include the more populous areas of England in our study.

A number of other data sources were employed to provide specific variables. Prominent amongst these was data on windiness provided by the FC[11] and digital maps of Environmentally Sensitive Area borders provided by MAFF. The principal supplementary data source was surveys conducted for this project and reported subsequently in this thesis, the structure of which we now consider.

1.3 STRUCTURE OF THE THESIS

This thesis is divided into three sections concerning respectively woodland, agriculture and a CBA comparison of the two. Section A opens with a consideration of the recreation value of woodland. This is subdivided into an appraisal of methods for the monetary evaluation of woodland (chapter 2), a review of previous evaluation studies (chapter 3), presentation of our own studies (chapter 4) and GIS-based analysis transferring results from these various evaluations to the case study area (chapter 5). The focus of attention then shifts to timber as an evaluation model is constructed (chapter 6) and applied to newly estimated yield models (chapter 7). The section, and with it our analysis of woodland values, is concluded by extending the definition of values to include the net benefits of carbon sequestration provided by forests (chapter 8).

Section B shifts the focus of attention to agriculture presenting models of both the farm gate and social values of production (chapter 9).

Section C opens by synthesising the preceding chapters and comparing woodland with agricultural values. Both market and social perspective assessments are presented (chapter 10). This analysis identifies a number of interesting results from which policy implications and conclusions are drawn and presented (chapter 11).

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[11]In the person of Chris Quine at the FC's Northern Research Station, Roslin to who we are grateful for cooperation, accommodation and hospitality.

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SECTION A: FORESTRY

Chapter 2: Recreation: Valuation Methods

2.1: INTRODUCTION

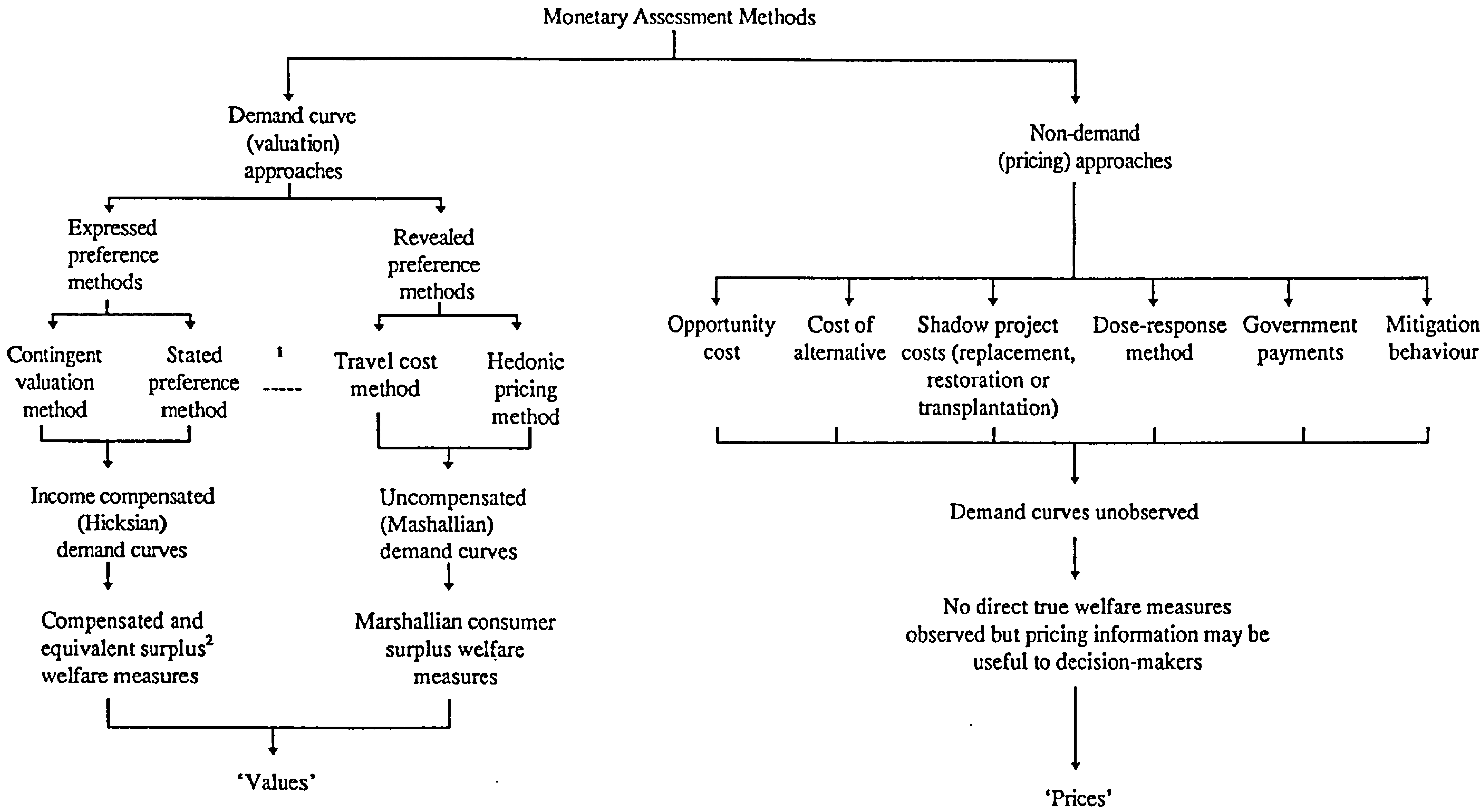
At the heart of Cost-Benefit Analysis (CBA) theory lie two basic principles (Pearce, 1984): firstly that, as far as possible, all the costs and benefits arising from a project should be assessed; and, secondly, that they should be measured using the common unit of money. While these seem commonsense precepts, in application both principles raise highly complex problems. The issue of complete appraisal is, when taken to the extreme, ultimately insoluble in a world ruled by the laws of thermodynamics where, as noted by commentators such as Price (1987) and Young (1992), everything affects everything else. For real world decisionmaking, practical rules regarding the limits of appraisal are needed. Such rules are the stuff of numerous project appraisal guidelines, for example the Treasury's 'Green Book' (H.M. Treasury, 1991), whereas our research focusses upon the second principle of monetary evaluation.

In discussing approaches to the monetary evaluation of environmental preferences we first identify a wider global family of monetary assessment methods (see figure 2.1). This comprises both the formal 'valuation' methods discussed below and a quite separate family of ad-hoc 'environmental pricing' techniques[1]. In theoretical terms 'valuation' and 'pricing' approaches are quite dissimilar. Whereas the former are based upon individuals preferences and yield conventional, neoclassical, welfare measures (hence the term 'valuation' methods), the 'pricing' techniques are much more akin to market price observations. A typical example of such a technique is given by the use of asset replacement, restoration or transplantation costs in project appraisals involving environmental assets (Buckley, 1989). While it has been argued that such methods provide heuristic tools for the appraisal of projects, policies or courses of action (Turner, Bateman and Brooke, 1992), pricing techniques reflect the costs of environmental protection alone to the exclusion of benefits. In considering only prices rather than values, decisionmakers are in danger of making incorrect choices[2]. Certainly such

[1]Critical reviews of these pricing approaches are given (in ascending detail) in Bateman (1992, 1995a and 1995b).

[2]As an interesting recent example of how pricing methods may give little practical guidance to a decision, Medley (1992) refers to the Department of Transport's pricing of a motorway tunnel to avoid a cutting through the Twyford Down SSSI in Hampshire. At £70 million this was considered too expensive and abandoned without any appraisal of the benefits of such an alternative being undertaken.

Figure 2.1: Methods for the monetary assessment of non-market and environmental goods.



Notes: [1]. For an overview of the link between stated preference and travel cost methods see Bateman and Bryan (1994) or Adamowicz et al. (forthcoming).
[2]. Assuming a quantity constrained public good (see Bateman and Turner (1993) for further discussion).
Sources: Compiled from Bateman (1992); Turner, Pearce and Bateman (1994); and Bateman and Bryan (1994).

information is insufficient for adequate CBA appraisals. We therefore reject the use of 'pricing' techniques and turn to consider the more theoretically rigorous valuation methods.

The valuation or demand-curve (Bateman, 1992) methods all ultimately rely upon individuals preferences. However, within this genre two distinct categories of approach can be defined; methods based upon preferences which are revealed through purchases by individuals of market-priced allied goods; and methods which rely upon expressed preferences elicited through questionnaire surveys. Reliance upon market observations means that the revealed preference techniques yield Marshallian demand curves and consumer surplus welfare estimates while expressed preference methods should, in theory, give income-compensated, Hicksian demand curves associated with compensated (true) welfare measures (see subsequent discussion)[3].

This research concentrates upon the use of one method from each of these fundamental valuation approaches: the contingent valuation (CV) method (expressed preference) and the travel cost (TC) method (revealed preference). Both of these methods are highly appropriate and have been extensively used for the valuation of woodland recreation externalities.

Consideration was also given to the use of the hedonic pricing (HP) method and a theoretical/methodological paper was prepared (Bateman, 1993a) and a literature review undertaken[4]. The HP method is most appropriate for assessing the landscape amenity value of woodland and the author is currently undertaking such a study with colleagues. However, due to difficulties regarding obtaining data this work has only recently commenced and will therefore be incorporated into subsequent extension of this research. Consideration was given to the use of existing research by others, however, to date only one major HP study of UK[5] woodland has been completed (Garrod and Willis, 1992) and, after discussion with the authors, it was not felt appropriate to extrapolate these results (which referred to national averages) to the research in hand. Similarly use of the Stated Preference technique (Adamowicz et al., 1994) was not considered appropriate at this stage. While promising, this is a relatively new approach which has only come to prominence in this field during the course of the present research. Further consideration will be given to the method in the

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[3]While some discussion of this theoretical basis is given below, this is limited by space and further details are given in Mitchell and Carson (1989); Bateman and Turner (1993); and Hanemann (forthcoming).

[4]Unpublished; available from author.

[5]The author is sceptical regarding the validity of extrapolating results across national, economic and cultural borders.

future.

The remainder of this chapter presents theoretical and methodological reviews of the two chosen valuation techniques; the contingent valuation and travel cost methods. In both of these reviews we concentrate selectively upon those areas of theoretical and methodological interest to this particular research. For wider ranging assessments see, for the contingent valuation method; Hanley (1990) and Bateman and Turner (1992, 1993); and for the travel cost method, Bateman, Garrod and Willis (1992) and Bateman (1993a, 1993b).

2.2: THE CONTINGENT VALUATION METHOD

2.2.1: METHOD AND THEORETICAL BASIS

2.2.1.1: Introduction

Hanley (1990) identifies six distinct phases involved in the practical application of CV which we have interpreted as follows:

Stage 1: Preparation

i. Set up the hypothetical market asking individuals either how much they are willing to pay (WTP) or willing to accept (WTA) in respect of the proposed change in provision of the good in question.

ii. Define the elicitation method. In a WTP study the major alternatives are:
   - Open ended (OE); "how much are you willing to pay?". This approach produces a continuous bid variable and may therefore be analysed using least squares approaches (OLS).
   - Dichotomous choice (DC); "are you willing to pay £X", the amount X being systematically stepped across the sample to test individuals' responses to different bid levels. This approach produces a discrete bid variable and requires logit-type analysis.
   - A variant upon the dichotomous approach is to supplement the initial question with an iterative second round (double-bound) question (see Hanemann et al., 1991). Further bounds may also be used (Langford, Bateman and Langford, 1996).
   - A further variant is to use an iterative bidding (IB) game moving from an

initial suggested bid level to a final open-ended response for which continuous variable estimation methods are appropriate.

- Other elicitation methods include the use of payment cards although these are less common in recent studies.

iii. Provide information regarding:
- the quantity/quality change in provision of the good
- who will pay for the good
- who will use the good.

iv. Define the payment vehicle, for example:
- higher taxes
- entrance fees
- donation to a charitable trust

Stage 2: Survey

Obtaining responses to the questionnaire. Interviews can be either on-site (face to face; users only), house to house (face to face; users and non-users) or by mail/telephone (remote; users and non-users).

Stage 3: Calculation

Calculate the mean WTP (or WTA) from responses. Some practitioners omit 'protest' votes[6], and/or use trimmed means at this stage. In a dichotomous choice format experiment the mean is obtained by calculating the expected value of the dependent variable (WTP or WTA)[7].

Stage 4: Estimation

A bid curve can be estimated to investigate the determinants and thereby validity, of WTP bids. For a continuous question format OLS estimation techniques are often employed. Typically, in WTP scenarios, the bid curve will relate bids to visits, income, socioeconomic

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[6]Respondents who refuse to state a WTP or WTA for an asset (or state extreme amounts) are commonly termed 'protest voters'. They should not be confused with the respondents who state a considered zero valuation for the good in question. A high proportion of protest votes may well signify a fundamental weakness in a study (see Sagoff, 1988; Eberle and Hayden, 1991; and discussions of strategic bias below).

[7]See, for example, Kriström (1990a) or Bateman et al. (1995a).

factors, and other explanatory variables. A parameter to accommodate environmental quality of the site may also be estimated. There is no theoretically correct form for the bid function. However, if a log-log form is chosen then the coefficients are elasticities. In such a case the bid curve allows us to estimate changes in mean WTP arising from changes in environmental quality. Indeed if the other relationships are sufficiently stable then we can use this curve to evaluate changes to other strongly related environmental goods, for example, the impacts of tree quality change upon overall woodland quality.

If a dichotomous payment format has been used then a logit or similar[8] approach is required, relating the probability of a yes answer to each suggested sum to the explanatory variables listed above.

Stage 5: Aggregation

This is required in order to extrapolate from sample mean WTP to total value. This entails decisions about, for example, moving between household and individual data, and distinguishing the relevant population.

Stage 6: Appraisal

Was the CV successful?

To answer the question posed in stage 6 we need to consider the theoretical acceptability of the evaluation estimates produced by CV[9].

2.2.1.2: Welfare change measures and the CV: a theoretical overview

In estimating monetary values for environmental resources we are concerned with how changes in the provision of environmental public goods impact upon individuals utility. Traditionally the welfare gain or loss from such changes of provision have been approximated by changes in consumer surplus[10]; the area underneath the ordinary (Marshallian) demand

[8]Alternatively a probit approach may be used, see Cameron and James (1987), Cameron (1988).

[9]Bateman and Turner (1993) also briefly address wider issues of institutional, practical and financial acceptability.

[10]References to 'consumer surplus' throughout this (and subsequent) chapters refer to the Marshallian consumer surplus measure.

curves and above the price level[11].

The Marshallian demand curve tracks the 'full price effect' which occurs when the provision of a good changes. Typically it has been used to show how much the quantity consumed of a normal good increases when its price falls. A practical problem therefore arises in estimating the Marshallian demand curve for an unpriced environmental public good. Without private property characteristics, such as rival consumption and excludability, a good cannot be traded in a market and the price/consumption information required to estimate the Marshallian demand curve will not be directly observable. One solution is to investigate a surrogate market, for example, analysing incurred travel costs as a proxy for the recreational value of an open-access leisure site and indeed the TC (discussed subsequently) is a consumer surplus method. However, a further theoretical problem remains in that the presence of income effects mean that consumer surplus itself can give an inaccurate measure of the welfare change resulting from a change in good provision.

In the case of environmental public goods the individual is usually faced with a quantity rather than a price constraint, the good often being unpriced. Furthermore, these goods often have higher income elasticities than those associated with many market goods (Bateman et al., 1992; Kriström and Riera, 1996). The consequently large income effect arising from a change in quantity provision may undermine the consumer surplus measure of welfare change. In order to move from the ambiguity of consumer surplus to a theoretically more accurate measure of welfare change we therefore need to compensate for the income effect by holding real income constant, i.e. moving from using the ordinary Marshallian demand curve to the compensated (Hicksian) demand curve.

The Hicksian approach evaluates welfare change as the money income adjustment necessary to maintain a constant level of utility before and after the change of provision. Two such welfare change measures are feasible for such an approach. The 'Compensating Variation' (CV) is the money income adjustment (welfare change) necessary to keep an individual at his initial level of utility (U_0) throughout the change of provision, while the 'Equivalent Variation' (EV) is the money income adjustment (welfare change) necessary to maintain an individual at his final level of utility (U_1) throughout the provision change.

[11]Price may be zero or positive dependent upon the property rights of the good. In the case of environmental goods we are usually faced with unpriced, quantity constrained, public goods. For an introductory text see Johansson (1991) and for further reading see Just et al. (1982) and Johansson (1987).

We therefore have two approaches to measuring welfare changes. Furthermore these changes can be either positive (a welfare gain) or negative (a welfare loss) giving us four possible scenarios. For a proposed welfare gain (i.e. a change in provision which increases utility, e.g. more recreation; less pollution; etc.) the CV measure tells us how much money income the individual should be willing to give up (WTP) to ensure that the change occurs[12] while the EV measure tells us how much extra money income would have to be given to an individual (WTA) for them to attain the final improved utility level in the absence of the provision change occurring[13]. For a proposed welfare loss (i.e. a change in provision which decreases utility, e.g. less recreation; more pollution; etc.) the EV measure will now show how much an individual is WTP to prevent the welfare loss occurring[14] while the CV measure now shows individuals WTA compensation for allowing the welfare loss to occur[15].

These variation measures (CV and EV) only strictly apply where the consumer is free to vary continuously (i.e. non-discretely) the quantity of the good consumed. Where the consumer is constrained to consume only discrete or fixed quantities (as for most environmental public goods) then we should consider compensating *surplus* (CpS) and equivalent *surplus* (ES) measures in place of CV and EV respectively. Bateman and Turner (1993) discuss in more detail the relationship between welfare measures for price and quantity constrained goods.

The upper panel of figure 2.2 shows a utility curve analysis of welfare gain and loss measures in the context of an unpriced, quantity constrained environmental good X_1. Provision of X_1 is shown on the horizontal axis while the vertical axis shows income as a money-composite of all other consumption X_0. Because X_1 is unpriced, the budget line is shown as the horizontal line $\bar{X}$ with initial consumption of X_1 being quantity rather than price constrained at Q_0 corresponding to point A on initial utility curve U_0[16]. Suppose that a

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[12]i.e. the loss of money income which, after the increase in provision, returns the individual to his initial lower utility level.

[13]i.e. the increase in money income which raises the individual to the same final utility level as if the foregone welfare gain in provision had occurred.

[14]i.e. the maximum amount of money income which the individual is prepared to give up to prevent the welfare loss occurring, leaving him as well off as if it had occurred (at the final, lower utility level).

[15]i.e. the increase in money income which returns the individual to his initial (higher) utility level given that the welfare loss change in provision does occur.

[16]Note that equilibrium is not achieved at a point tangential to a utility curve. Although the individual would prefer to be at such a point (i.e. more along X from point A to a tangential point with a higher utility curve), consumption of X_1 is exogenously constrained at Q_0.

welfare gain is proposed, increasing provision of X_1 from Q_0 to Q_1. This is shown as a move from point A on U_0 along the budget line to point B on U_1. This corresponds to the full price effect shown by the Marshallian demand curve DD in the lower panel and the corresponding increase in consumer surplus shown by the shaded areas b + c. Despite X_1 being itself unpriced, its increased provision will still have an income effect by releasing some of that income previously spent upon priced goods (e.g. if Q is recreation then its increased provision relieves spending upon other priced recreation goods). Consumer surplus is therefore only an approximate measure of the true welfare change. We can compensate for the income effect and obtain a correct welfare change measure by asking how much the individual is WTP to ensure that the increase in provision does occur. The individual should be prepared to give up the amount of income BC which returns him to point C on his initial utility curve U_0 but with the increased provision Q_1. The corresponding compensated demand curve h_0h_0 is shown in the lower panel and it is the shaded area c under this curve which correctly measures the welfare change for this scenario (CpS_{WTP}).

Now suppose that the same proposed welfare gain (Q_0 to Q_1) is not implemented. The authorities could still raise the individual's utility from U_0 to U_1 by increasing money income by the amount AD (the equivalent value of extra income which individuals are WTA to forego the welfare gain change in provision). This moves the individual to point D on U_1 and maps out the compensated demand curve h_1h_1 in the lower panel. The correct welfare measure for this scenario is therefore the equivalent surplus ES_{WTA} (the shaded area a + b + c in the lower panel). Note then that for a welfare gain we have CpS_{WTP} < consumer surplus < ES_{WTA}, in short WTP < WTA.

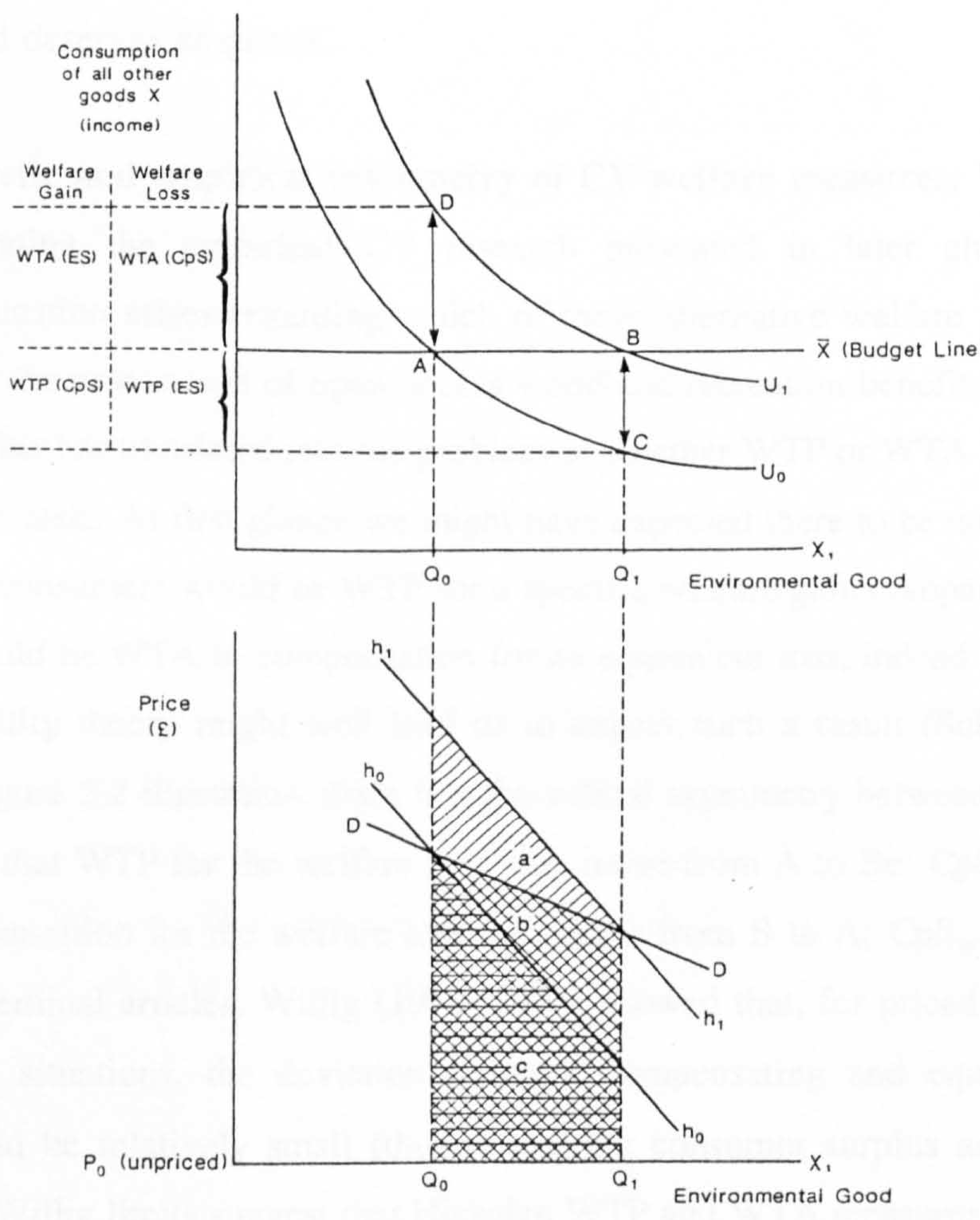
Now consider a proposed welfare loss, say a decrease in the provision of the same unpriced environmental good from Q_1 to Q_0. Here the individual will start at point B and the initial utility curve will be U_1. Faced with a fall to point A on new utility level U_0 the individual will be WTP the amount BC to avoid the loss (ES_{WTP})[17]. However, if the welfare loss change in provision does occur, then the authorities can still compensate the individual by giving him extra income AD to return him to his initial utility level U_1 (CpS_{WTA})[18]. Note

[17]This is an equivalent surplus measure as the welfare change is measured from the new utility curve, here U_0.

[18]Similarly this is a compensating surplus measure as the initial utility level, U_1, is our welfare measure reference.

that for the welfare loss we now have ES_{WTP} < consumer surplus < CpS_{WTA}. Therefore, for either gains or losses, the WTA measure exceeds WTP, however, the derivation of these measures (i.e. CpS or ES) changes[19].

Figure 2.2: Compensated welfare change measures for an unpriced quantity constrained good



Source: Bateman & Turner (1993)

In summary, as we have seen, there are theoretical problems with the consumer surplus measure of welfare change. Yet, because of the impossibility of mapping utility functions, consumer surplus measures have often been calculated as best practical estimates

[19]Bateman and Turner (1993) present an expenditure function approach to assessment of these welfare measures.

of welfare change. The CV approach, in eliciting explicit statements of how much income consumers are WTP to ensure that a welfare gain occurs (or prevent a welfare loss occurring) or how much income they are WTA to endure a welfare loss (or forego a welfare gain) is, in theory, directly estimating the true Hicksian welfare measures of these changes (see Bateman and Turner (1993) for formal proof). Although in later sections we address several important methodological criticisms of the empirical method, this theoretical ability to estimate true welfare measures represents a considerable potential advance over other approaches and deserves emphasis.

2.2.1.3: Theoretic and empirical asymmetry of CV welfare measures: WTP v. WTA

In planning the empirical CV research presented in later chapters an initial fundamental question arises regarding which of these alternative welfare measures is most appropriate for the assessment of open-access woodland recreation benefits. In the majority of CV studies this has translated into the problem of whether WTP or WTA measures are best fitted for such a task. At first glance we might have expected there to be no difference in the amount which consumers would be WTP for a specific welfare gain compared to the amount which they would be WTA in compensation for an equivalent loss, indeed certain aspects of neoclassical utility theory might well lead us to expect such a result (Schoemaker, 1982). However, as figure 2.2 illustrates, there is a theoretical asymmetry between WTP and WTA measures such that WTP for the welfare gain (i.e. move from A to Be; CpS_{WTP}) is exceeded by WTA compensation for the welfare loss (i.e. move from B to A; CpS_{WTA}).

In his seminal articles, Willig (1973, 1976) showed that, for priced normal goods in most plausible situations, the deviation between compensating and equivalent variation measures should be relatively small (thus promoting consumer surplus as a valid welfare measure). The Willig limits suggest that Hicksian WTP and WTA measures should generally lie within 2% either side of the Marshallian consumer surplus. These results using Hicksian analysis were formulated for price changes and Hicks (1943) shows that this asymmetry is, in theory, slightly more pronounced for unpriced goods subject to quantity constraints (see Bateman and Turner, 1993).

Nevertheless, these limits in no way provide a theoretical explanation of the very wide WTP/WTA asymmetry found in empirical testing. Table 2.1 shows that in practice CV studies have recorded very wide divergence between WTP and WTA raising considerable concern about the validity of the method. We therefore need to consider whether such a pronounced empirical asymmetry is indicative of a fundamentally flawed methodology or whether it has any theoretical plausibility.

Table 2.1: Empirical divergencies between WTP and WTA

Study		*WTA/WTP*
Knetsch & Sinden (1984)		4.0
Coursey, Schulze & Hovis (1983)	(i)	3.8
	(ii)	1.6
Brookshire, Randall & Stoll (1980)	(i)	1.6
	(ii)	2.6
	(iii)	6.5
Bishop & Heberlein (1979)		4.8
Banford, Knetsch & Mauser (1977)	(i)	2.8
	(ii)	4.2
Hammack & Brown (1974)		4.2

Source: adapted from Pearce & Markandya (1989).

Reverting back to variation measures to avoid discontinuity problems, the Willig formulae can be approximated as follows (Varian, 1984)[20]:

$$\frac{CS - CV}{|CS|} \simeq \frac{|CS|\,\eta}{2\,Y^{o}} \tag{2.1}$$

where
- CV = compensating variation
- CS = Marshallian consumer surplus
- η = income elasticity of demand
- Y^{o} = initial income (expenditure)

[20]The approximation formula is only valid if $|CS|/Y^{o}$ is less than 0.9 (Boadway and Bruce, 1984: pp.216-220), i.e. expenditure on the good (and the associated welfare measures) cannot be too high relative to the consumers income if this is to hold.

Willig (1973, 1976) shows that, for the priced good case, such errors are likely to be small[21]. However, this error will clearly increase with greater income elasticity[22]. More importantly in the environmental context, when we consider unpriced goods then the income elasticity of demand term is not strictly relevant. Randall and Stoll (1980) show that income elasticity (η) should be replaced by the 'price flexibility of income' (ε) and reformulate the Willig limits as (for a welfare gain i.e. CV is given by WTP):

$$\frac{CS - WTP}{CS} \simeq \frac{\varepsilon CS}{2Y} \tag{2.2}$$

and

$$WTA - WTP \simeq \frac{\varepsilon CS^2}{Y} \tag{2.3}$$

where:

CS	=	Marshallian consumer surplus
WTP	=	Willingness to pay: CV for a welfare gain (CpS_{WTP} for a non-continuous consumption function)
WTA	=	Willingness to accept compensation: EV for a welfare gain (ES_{WTA} for a non-continuous consumption function)
Y	=	Mean respondents income
ε	=	Price flexibility of income

Randall and Stoll (1980) estimate ε in a manner analogous to an ordinary income elasticity by regressing WTP upon the quantity of the good, income and other significant explanatory variables. From this they estimated that, under reasonable assumptions, measures of WTP and WTA for quantity constrained goods should be within 5% of each other. CV practitioners concluded from this that the wide empirical divergence of WTA above WTP was merely a methodological glitch which could effectively be ignored and that WTP sums were

[21] A result confirmed by Just et al. (1982) who also show that the Willig approach may be generalised to the multiple price change case (pp.375-86).

[22] This error will also increase for aggregate populations where there are large variations in income and/or income elasticity of demand between consumers.

valid approximations to WTA (e.g. Desvousges et al., 1983).

In a significant re-analysis of theory, Hanemann (1986, 1991) shows the Randall and Stoll (1980) derivation of the price flexibility of income (ε) to be inexact, demonstrating instead that:

$$\varepsilon = \frac{\eta}{\sigma} \qquad (2.4)$$

where

η = income elasticity for the environmental good

σ = elasticity of substitution between this and all other goods

Using what they term "the not-too-unreasonable values of, say, $\eta = 2$, and $\sigma = 0.1$", so that $\varepsilon = 20$, Mitchell and Carson (1989) apply the above formulae to their earlier empirical work on the evaluation of water quality improvements (Mitchell and Carson, 1981). In this work they found an average WTP of $250 (with average income = $18,000). We can therefore rewrite equation (2.2) as: $\varepsilon CS^2 - 2Y.CS + 2Y\,(WTP) = 0$. Substituting in values for ε, Y and WTP gives consumer surplus (CS) = $300 and substituting this into equation (2.3) gives WTA = $350. On the basis of these assumptions WTA is shown to be some 40% larger than WTP in this example. Furthermore, while they state that higher values of η are unlikely, Mitchell and Carson (1989) state that "much smaller values of σ for a number of public goods are quite plausible". Using the same empirical data we can deduce that, for WTA to be double WTP, requires $\sigma = 0.0625$; while for WTA to be triple WTP requires $\sigma = 0.05$. Such substitution elasticities describe progressively superior goods (some environmental goods appear to fit this profile rather well).

In an important extension of his work in this area, Hanemann (1991) simulates WTP and WTA levels for a generalised CES utility model under a variety of assumptions[23]. Hanemann confirms the inverse relationship between the elasticity of substitution measure and the WTA/WTP ratio, i.e. for unique and irreplaceable environmental goods (Hanemann cites Yosemite National Park as an example) with very low elasticity of substitution. In this

[23]See Deaton and Muellbauer (1980) for details of this and other utility systems.

context, we should expect WTA to be much greater than WTP. Hanemann also demonstrates that the same result still holds with a much higher elasticity of substitution ($\sigma \simeq 1$) where the ratio of WTP to income is high, i.e. where the proposed change matters a lot to the individual concerned. Under both these scenarios, Hanemann demonstrates that standard theory can explain levels of WTA more than five times the magnitude of WTP. Furthermore the Hanemann formula confirms that, where elasticity of substitution is not low and the WTP/income ratio is not excessively high (a scenario typical of many market priced private goods), then WTP and WTA will not diverge very significantly.

These findings extend rather than refute the original Willig limits. Indeed they show that the observed WTP/WTA asymmetry does have a theoretical basis and we should expect such asymmetry to occur where we are evaluating environmental goods which are in some significant way unique, irreplaceable or lacking substitutability. Such asymmetry, rather than being a methodological glitch, should actually be interpreted as theoretical backing for the internal consistency of the CV.

While there appears therefore to be a strong case in economic theory for observed empirical CV results, we also recognise that other arguments stemming from the literature of psychology have been put forward to explain the apparent WTP/WTA asymmetry. We highlight three such arguments before formulating our conclusions.

i) Rejection of the WTA property right

In a WTP format experiment, respondents may feel that they (or the CV researchers) have no right to, in effect, sell the environmental good being valued. This result in either a refusal to give a WTA sum, i.e. a 'protest vote' (Sagoff, 1988; Eberle and Hayden, 1991), or an inflation of that sum so as to indicate that no level of compensation is acceptable, thereby preventing any loss of the good. Bishop and Heberlein (1979) note that such protest votes are far less common in 'real' WTA situations where respondents are actually offered cash compensation, indicating that this may in some way be a methodological artifact of hypothetical markets (see subsequent discussions of hypothetical bias).

Nevertheless, there is evidence that respondents do perceive public goods such as environmental assets in a different manner to their treatment of private goods. Turner (1988a/b) argues that individuals possess both private and public preferences. This arises out of the complex array of diverse services which environmental goods can exhibit. The Total

Economic Value concept (Pearce and Turner, 1990a) incorporates conventional utilitarian use-values with option[24] and non-use (bequest and existence) values. Turner (1988a/b) argues that the combination of private and public preferences inherent in the evaluation of environmental goods is fundamentally distinct from the market pricing of a private good. In particular the respondent will value the continued preservation of environmental assets for enjoyment by future generations. This may in turn cause a rejection of the compensation-for-loss principle inherent in the WTA question.

ii) Inexperience and risk aversion

Market prices are the result of consumers repeated evaluations of goods. However, the CV scenario effectively gives respondents only one opportunity to evaluate what is often a high-preference good. Respondents therefore do not have the advantage of past experience to call upon in determining their valuations. Hoehn and Randall (1987) argue that in such situations of imperfect information, risk aversion will tend to raise respondents WTA responses in an attempt by them to ensure continued provision of the good. Such a proposition was supported in tests by Coursey et al. (1986) where it was shown that WTA sums for a particular good tended to decline over repeated CV trials, i.e. as valuation experience fed back into the evaluation process.

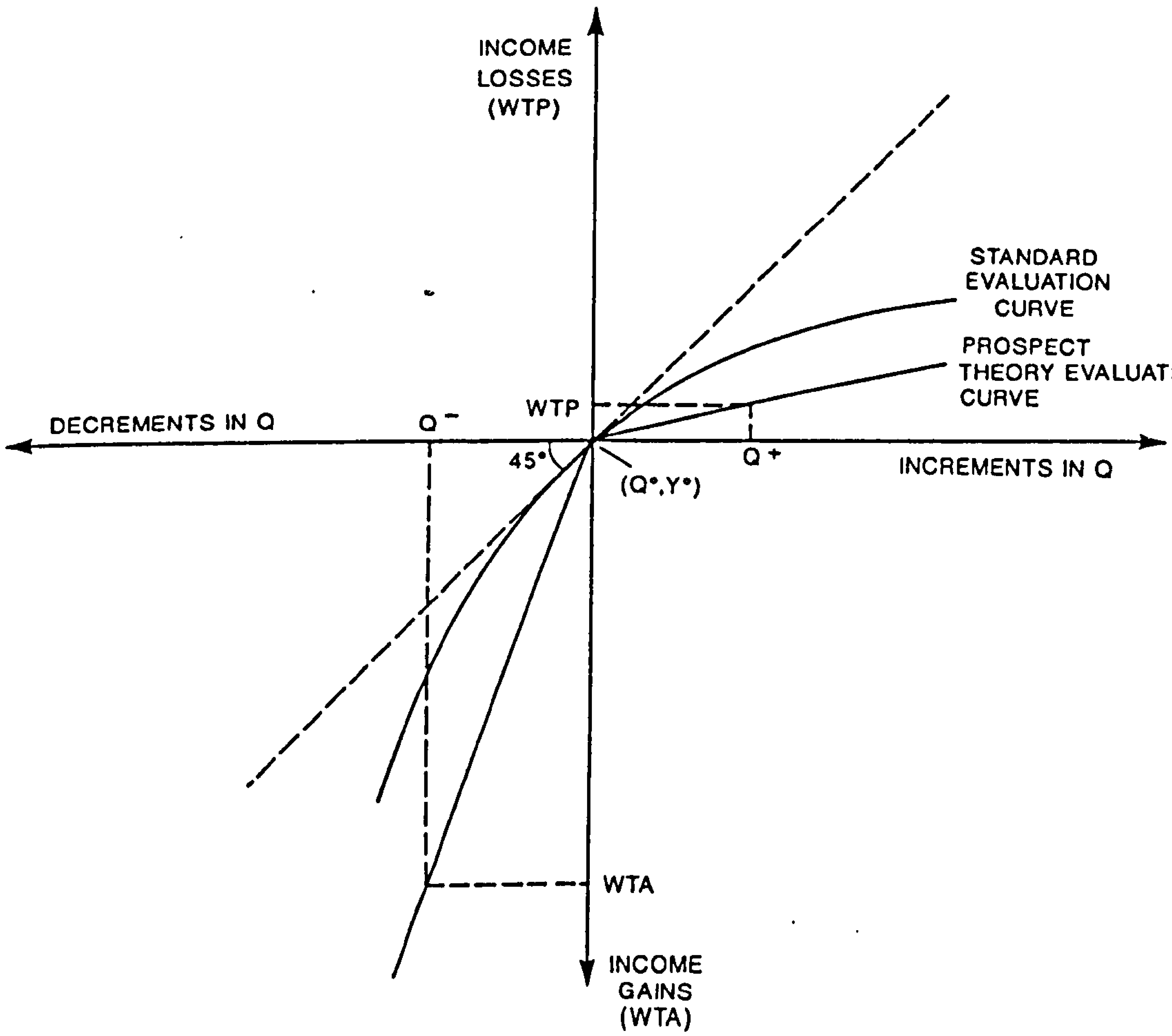
iii) Prospect theory

The neoclassical Willig-type divergence between CV (WTP) and EV (WTA) is illustrated as the smooth 'standard evaluation curve' in figure 2.3. Here an individual is initially at the origin with income Y^0 and an initial non-zero allocation of an environmental good Q equal to Q^0. Under standard theory, for an increment in Q (from Q^0 to Q^+) the individual has a WTP equal to the distance Y^0WTP, while for an equal decrement in Q (from Q^0 to Q^-) the individual has a WTA equal to the distance Y^0WTA. The relevant factor here is the smooth nature of the standard evaluation curve and the consequent relatively small divergence between WTP and WTA. In their 'Prospect Theory', Kahneman and Tversky (1979) postulate that individuals will have a psychological affinity for the status quo such

[24]Typical references to option value include Weisbrod (1964); Cicchetti and Freeman (1971); and Krutilla and Fisher (1975). However, Kriström (1990b) argues that the concept of an option value can be traced back to Jeavons in 1888.

that, whilst they may be willing to pay for increments, they are very unwilling to contemplate a reduction in their initial allocation of the good in question[25]. In such a model the Prospect Theory evaluation curve is kinked at the initial allocation 'reference point' such that WTA is related not to WTP but to that reference point and exceeds WTP very significantly. In such a system gains and losses cannot be readily traded off, for example, a transfer from one individual to another would, given common preferences and endowments, always lower collective utility.

Figure 2.3: Valuation of changes in the provision of an environmental good



Source: Bateman (1995a) adapted from Brookshire et al. (1980), Kahneman and Tversky (1979), Jones-Lee (1989)

[25]The roots of such an idea may be traced back to Adam Smith (1790) who states that "We may suffer more, it has already been observed, when we fall from a better to a worse situation, than we ever enjoy when we rise from a worse to a better".

These ideas are developed by Kahneman et al., (1990) and Tversky and Kahneman (1991) into a model of reference-dependent preferences. In recent work by the author and colleagues we tested this model using real trades with private goods, i.e. removing the hypothetical and public goods issues which were suspected to be the cause of these non-standard results. However, our findings clearly showed that even under these carefully controlled conditions significant reference point effects continued to occur (Bateman et al., 1995b and forthcoming a).[26] Given this we can no longer identify the nature of the CV experiment as the sole cause of these effects. Rather this seems a general problem for microeconomic theory (which may be exacerbated through poor CV design) which we address in other research and is not within the remit of this study.

2.2.1.4: Determining the appropriate welfare measure

The above review suggests that both economic and psychological theory provides reasons why WTA may exceed WTP sums. This commonality of effect causes problems if we wish to compare results using the two measures. As a consequence CV practitioners have argued for WTP formats and provision gain scenarios (Mitchell and Carson, 1989; Harris and Brown, 1992) as a method of reducing psychological effects and thereby enhancing economic validity.

While this generally seems sensible there is a potential credibility problem where the provision change is demonstrably negative and compensation is the expected payment format. Consequently in our subsequent research we generally use a 'WTP for gain' approach when assessing recreationalists. However a 'WTA for loss' scenario is used in a small experiment assessing farmers required compensation levels for providing such woodlands.

2.2.2: METHODOLOGICAL ISSUES

2.2.2.1: Introduction

Those methodological issues most pertinent to the CV can be roughly divided into validity, reliability and bias categories (Bateman et al., 1991). Validity refers to the degree to which the CV evaluation correctly indicates the 'true' value of the asset under investigation, bias being a common cause of low validity. Reliability refers to the consistency

[26]Note that Peterson et al. (1996) produce contrary results in which transitivity is not violated. However, their experiment is somewhat different as it compares public with private decisionmaking.

or repeatability of CV estimates. Of course reliability and validity need not be synonymous, for example, a particular CV instrument may, in repeated trials, yield a consistent value estimate for a particular asset. However, if these trials are all subject to a bias then the results will not be valid.

We begin this review by a brief consideration of reliability issues. Problems of bias are then addressed in greater depth reflecting the academic interest in this area. The methodological review is then concluded with an assessment of the issue of validity.

2.2.2.2: Reliability

In CV surveys reliability is associated with the degree to which the variance of WTP responses can be attributed to random error, with reliability being inversely related to the degree of non-randomness. Notice that reliability says nothing about the validity of estimates.

Variance in WTP responses derives from three sources; true random error; sampling procedure and the questionnaire/interview itself (instrument variance). True random error is essential to the statistical process while induced sampling procedure error is a potential problem inherent in any statistical survey and can usually be acceptably minimised by ensuring that a statistically significant sample size is used. It is instrument variance which is of most concern here.

Assessing Reliability

Several commentators (Mitchell and Carson, 1989; Kriström, 1990a; Hanley, 1990) advocate the subsequent retesting of a particular CV scenario as a test of the reliability of estimates from an initial test. According to Kriström (1990a), "If the same experiment is repeated a number of times with different samples and careful statistical analysis reveals no correlation between the variables collected then this is a warning flag" indicating low reliability. Few such replicability tests have been carried out, mainly due to the high resource costs involved. However, one notable exception is provided by Carson et al., (1995) who retest their earlier findings (Carson et al., 1992) concerning WTP to protect Prince William Sound, Alaska from future oil spills like that from the grounding of the Exxon Valdez on 24th March, 1989. The two studies involved independent samples of interviews taken over two years apart concluding that the response distributions did not differ significantly between these two samples. Other studies by Loehman and De (1982); Heberlein (1986); Loomis (1989, 1990); Carson and Mitchell (1993) and Epp and Gripp (1993) generally support the reliability of CV instruments.[27] Unfortunately time and resource constraints prohibited retesting of our empirical results and so no further consideration is given to this area of research.

2.2.2.3: Bias Issues

CV is an expressed-preference valuation method and as such is inherently susceptible to various types of bias which we have subdivided into cognitive, procedural and instrument bias.

General Bias'

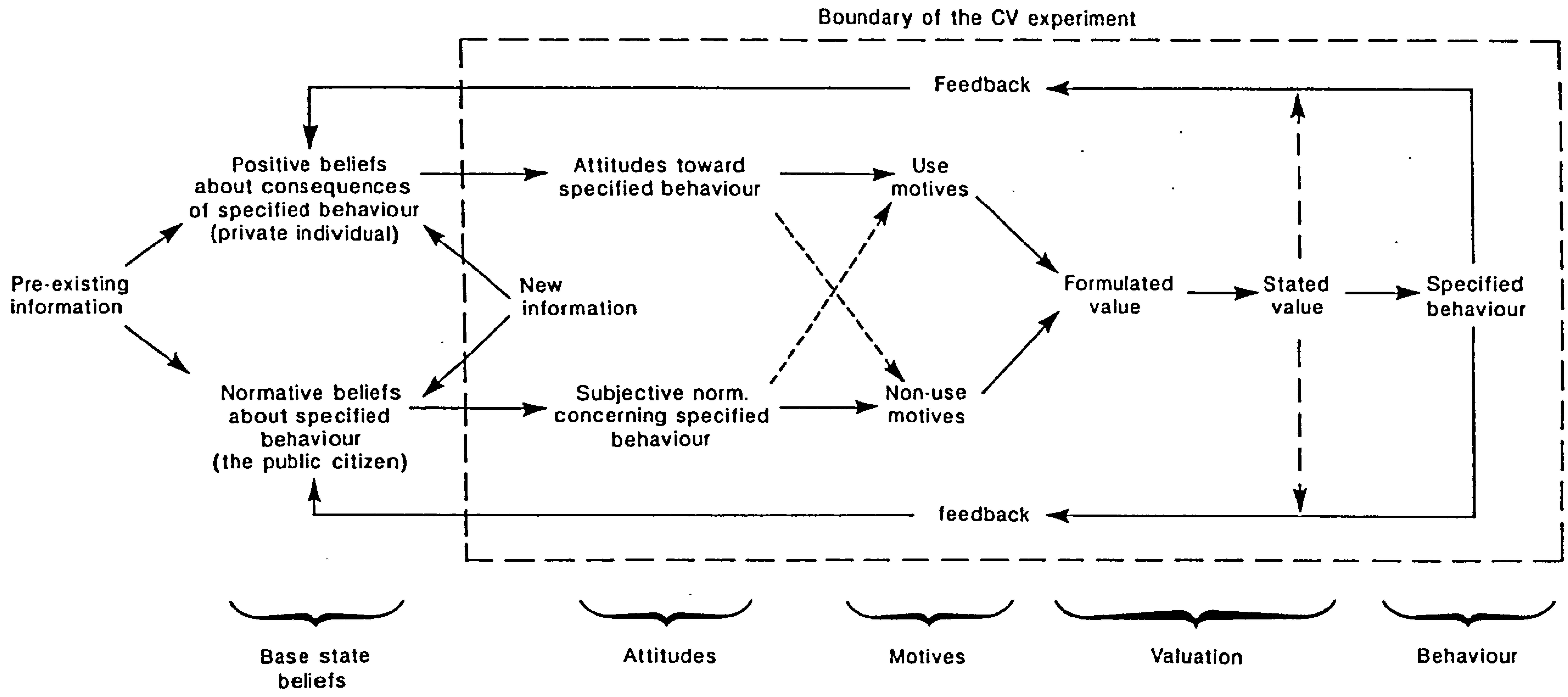
i. Introduction: The Valuation Process

Standard neoclassical economic theory is based upon a relatively simple model of "rationale economic person", dominated by the concerns of self interest. Under such a utilitarian theory donations to environmental groups can be seen as enlightened self-interest while charitable acts contribute a warm glow of impure altruism towards the individuals quest to maximise his income-constrained utility function (Andreoni, 1990). Here values are simply reflections of the individual preferences arising from such precepts and the measure of those values in the individuals willingness to pay for the good or service in question.

Many commentators have criticised this rather simplistic definition of human nature. From the discipline of environmental economics critics have highlighted the multifaceted nature of values. Many goods, particularly those provided by the environment, provide much more than the basic instrumental use values implicit in simple utilitarian models (Pearce and Turner, 1990a). A more fundamental critique comes from the crossover of environmental economics with psychology and resultant attitude/statement/behaviour models of individuals as illustrated in figure 2.4.

[27]Mitchell and Carson (1989) also highlight similar findings from non-CVM survey re-tests.

Figure 2.4: An attitude/statement/behaviour model of the individuals valuation process



Source: Various, see text.

The attitude/statement/behaviour model illustrated in figure 2.4 draws upon a number of sources (Fishbein and Ajzen, 1977; Hoehn and Randall, 1987; Mitchell and Carson, 1989; Harris and Brown, 1992; and Bateman and Turner, 1993). It presents a more complex and realistic view of the individual than that underpinning 'rational economic person' allowing us to consider both the pre-existing cognitive state of respondents prior to the CV survey, and how that state alters as a result of the experiment. In our attitude/statement/behaviour model the pre-survey base-state of the individual is formed from the set of prior information held by that person. This base-state is influenced by two dialectics through which information is interpreted: (i) positive versus normative beliefs (what is and what should be); and (ii) the schism between the preferences of the private individual and those of the public citizen. This latter factor may be one of considerable conflict but is of major relevance to CV research given that few other approaches are capable of potentially estimating those 'citizen preferences' so often ignored by the market (Blamey, 1996). If we generalise somewhat we can argue that these public citizen preferences will influence normative beliefs while private individual preferences will have most impact upon positive beliefs (Peterson et al., 1996).[28]

In the CV experiment the respondent is presented with new information which will be used to update the belief set. These beliefs will then form the individuals attitudes and norms concerning behaviour. Information, beliefs and attitudes all then feed into motivation. It is arguable that non-use (existence and bequest) values arise from non-use motives such as altruism (Randall, 1987) drawing upon normative beliefs whereas use values arise from positivist beliefs and attitudes. However, while these are likely to be the main routes of influence we can also imagine norms concerning instrumental goods and positivist ideas concerning non-use values.

These use and non-use motives combine and are expressed as the WTP sum within the CV valuation process (discussed below). This statement of value and the CV experience itself then feeds back either via behaviour (an actual payment) or, more usually, directly into the individuals positive and normative beliefs.

The transition to formulated and then stated value is the subject of theoretical analysis by Hoehn and Randall (1987). Here the respondent is seen as facing a two stage CV valuation process (i) value formation (ii) value statement. In the first stage the respondent

[28]Peterson et al. (1996) report empirical work suggesting that individuals use different utility functions for private choices to those used when they are asked to act as public agency decisionmakers.

attempts to determine his WTP for a good. Hoehn and Randall consider two factors inherent in CV style surveys: (i) imperfect information (and resultant uncertainty); (ii) time constraints. In the presence of either factor the individual will formulate a WTP which is lower than true WTP given perfect information and no time constraint. In moving from formulated to stated value the respondent has the opportunity to engage in a variety of strategic behaviour including both understatement and overstatement of formulated WTP (discussed subsequently). Hoehn and Randall see these various strategies as being chosen according to the elicitation method being used (OE; DC; etc). Accordingly one focus of the empirical work presented in subsequent chapters is the impact of elicitation method upon responses.

In summary we would argue that our attitude/statement/behaviour model is more realistic but also more complex and consequently less amenable to simple predictions than that of the "rational economic person" underlying standard neoclassical theory. The need to formalise such complex models and thereby improve the credibility of economic models of behaviour is an ongoing area of economic research (as witnessed by the contemporary vogue for experimental economics). However, such research lies beyond the remit of this study which, following Hoehn and Randall (1987), focusses upon the valuation stage of our model spanning between formulated and stated value in our CV studies and on to include actual behaviour in our TC research.

In the remainder of this section we consider the various general biases which may affect the transition from formulated to stated value.

ii. Hypothetical Bias

Irrespective of the chosen elicitation method, a basic question concerns whether the hypothetical nature of the contingent market itself induces bias into the question. There is debate about the very nature of any such hypothetical bias. Freeman (1986) sees the impact of an increasingly hypothetical scenario as being increased bid variance, while Mitchell and Carson (1989) extend this to reject the entire notion of hypothetical bias referring instead to situations of recognised specific bias and (discussed subsequently) and low model reliability. However, many commentators (Schulze et al., 1981; Bishop et al., 1983; Randall et al., 1983) are convinced that the use of hypothetical rather than real markets can in certain circumstances produce its own distinct bias problems.

Our opinion is that discussion of a distinct hypothetical bias is unhelpfully imprecise.

What is clear is that the hypothetical market presents respondents with the opportunity to shift their stated WTP away from formulated WTP. The real issue, we feel is whether the strategies involved conform to a perhaps extended view of economic theory or to some other competing psychological theory. In the former case we can accept stated WTP as having some economically acceptable link with true value while if the latter is true CV results are not admissible as some benefit cost indicator.

Research into the predictive ability of hypothetical markets has followed two paths: studies of the attitude/statement/behaviour relationship; and experiments examining the substitution of real for hypothetic markets.

Market research, political polls, consumer surveys and our own attitude/statement/behaviour model all operate on the premise that stated attitudes or intention are significantly reliable indicators of actual behaviour. In our model, each stage in the cycle influences the next. However, this influence is not perfect, for example, attitudes may not perfectly predetermine behaviour, while the feedback loops provide a dynamic adjustment system so that, for example, a recent visit to the countryside may well affect a respondent's WTP to preserve wildlife habitat (transformation value). This, however, is a reflection of reality present in the consumption of all goods, marketed or not, and need not pose a special problem for the CV technique.

Ajzen and Fishbein (1977) develop three hypotheses from their model indicating how the attitude-behaviour link can be maximised. Firstly, attitude will best predict behaviour where the two closely correspond. So, asking WTP for a general environmental improvement will be a poor indicator of WTP higher taxes for improving the water quality of a specific river. Scenario misspecification, either as constructed by the interviewer or as perceived by the respondent, will obviously cause bias. Secondly, the fewer the intervening stages between a component in the model and behaviour, the greater the predictive power of that component (Mitchell and Carson, 1989), i.e. stated value is a better predictor of behaviour than attitudes while attitudes are better behaviour predictors than beliefs because in both cases fewer influence relationships are involved. In a study of unleaded petrol consumption, Heberlein and Black (1976) found an attitude-behaviour correlation of just 0.12 but a stated value-behaviour correlation of 0.59. Thirdly, attitude will be a better predictor of behaviour when the respondent is dealing with familiar behaviour situations[29]. Hanley (1990) sees this as a source of error with respect to environmental goods where, unlike marketed goods, there is no opportunity to learn by experience of purchasing. However, he feels that, in the main, this error will be associated with WTA scenarios, where respondents will be very unfamiliar with the selling rather than purchasing role, and less significant in WTP situations with which respondents have both greater experience and empathy.

Bateman and Turner (1993) review a number of studies examining the potential effect of the hypothetical nature of CV markets (Schuman and Johnson, 1976; Bishop and Heberlein, 1979; Hill, 1981; Rowe and Chestnut, 1983; Bishop et al., 1984; Bishop and Heberlein, 1985; Heberlein and Bishop, 1986; Brookshire and Coursey, 1987; Dickie et al., 1987; Mitchell and Carson, 1989; Kealy et al., 1990). While there is empirical evidence for a divergence between formulated and stated value may be significant (particularly in WTA formats) there was no clear evidence that these could be attributed to some hypothetical bias. Following the assumptions underpinning the theoretical analysis of Hoehn and Randall (1987), the key factor in eliminating pure hypothetical bias is the credibility of the CV scenario and payment obligation. Where this holds recognised biases may still operate (e.g. free-riding; see subsequent discussion) but the measures obtained will still have theoretical validity i.e. they are biased but still related to true WTP. However, where there is a credibility gap and/or where psychological biases operate (e.g. anchoring effects; see subsequent discussion) CV results will not be valid benefit-cost indicators.

In formulating appropriate guidelines, Rowe and Chestnut (1982) argue that a credible CV instrument must be[30]: informative; clearly understood; "realistic by relying upon established patterns of behaviour and legal institutions"; and "have uniform application to all respondents". The further that a particular CV scenario moves from these precepts, for example, the less familiar the respondent is with the good or the construct of its valuation, then the more likely it is that such an instrument will have low credibility. Realism and familiarity are therefore at a premium in undertaking CV studies and have been a major

[29]Ajzen and Peterson (1988) extend these attitude-behaviour criteria by emphasising that behaviour must be under the volitional control of the respondent, that lags between the measurement of intention and prediction of behaviour will be problematic and that levels of generality in the measures of intention and behaviour should be identical, i.e. the extrapolation of intention towards one environmental asset as a predictor of intentions toward a wider asset set is highly dubious.

[30]See also the 'Reference Optimal Conditions' of Cummings et al. (1986).

objective in our design of the field experiments discussed subsequently. However, even if credibility is attained other biases may still arise, to which we now turn.

iii. Understatement of WTP

If an individual feels that a good will be provided irrespective of his response to a WTP question, or that the payments of others will be sufficient to secure provision then he will "pretend to have less interest in a given collective activity than he really has" (Samuelson, 1954) and will understate his WTP for that good, i.e. he will free-ride (Marwell and Ames, 1981; Brubaker, 1982). A similar result will be obtained where respondents feel that actual payments will (or should) be related to cost-shares rather than to WTP (Hoehn and Randall, 1987). Here respondents will state the expected cost if this is less than WTP and zero otherwise.

There have been a number of empirical investigations of the free rider theorem. Brookshire, et al., (1976) and Schulze et al., (1981) argue that, assuming that true WTP bids are theoretically normally distributed, then free-riding should disturb this causing, in a WTP scenario, a distribution bias towards zero. Using such an approach, Brookshire et al., (1976) test for and reject the presence of strategic bias. However, Rowe et al., (1980) criticise the underlying assumption of such a test stating that bimodal distributions can be posited upon the income characteristics of the respondent population. Certainly in a recent large sample experiment, Bateman et al., (1992) found highly skewed income and bid distribution. A more typical approach is adopted by Brubaker (1982) where respondents were asked to bid for a $50 shopping voucher under three scenarios, S_1 in which the n highest bidders were guaranteed a voucher, S_2 in which respondents were told that vouchers would be provided for all as long as the total WTP of all respondents exceeded a specific amount, and S_3 in which respondents were told that all those giving any positive WTP would receive a voucher. Brubaker assumed that S_1 would provide the true WTP, while S_2 had a weak incentive to free-ride compared to S_3 where a strong free-ride response was expected. The mean WTP results were (S_1 = \$33.99)>(S_2 = \$27.07)>(S_3 = \$23.96). These results appear to bear out the expectations of strategic behaviour. However, with further analysis, only the first two, S_1 and S_2, are significantly different at the 5% confidence level. This experiment tends to indicate that, while free-riding does occur, it appears to be less prevalent than standard neoclassical theory would predict and may not invalidate CV exercises. Table 2.2 compiles results from a number of these studies.

Table 2.2: Stated WTP as a percentage of true WTP in the presence of a free-rider incentive

Study	Percentage of true WTP[1]
Schneider and Pommerehne (1981)[2]	96
Marwell and Ames (1981)[2]	84
Brubaker [S_2] (1982)[2]	80
Christiansen (1982)[2]	79
Bohm (1972)[2]	74
Brubaker [S_3] (1982)[2]	71
Schneider and Pommerehne (1981)[3]	61

Notes: 1. The true WTP being measured in an auction where the winning bid(s) received the good.
2. In these experiments a group threshold WTP was required for provision, i.e. there was a relatively weak free rider incentive.
3. In these experiments provision of the good was guaranteed irrespective of the (non-zero) WTP sum offered by the respondent, i.e. there was a relatively strong free-rider incentive.

Source: Adapted from Mitchell and Carson (1989)

Table 2.2 indicates that where respondents were told that a certain threshold total WTP was required from the population before the good was provided (weak free-rider incentives) then stated WTP was between 71-96% of true WTP i.e. the extent of free riding is considerably less than standard theory might lead us to predict (Mitchell and Carson, 1989). The fact that stated WTP is still somewhat below 'true' WTP in such situations is not surprising and accords with the theoretical conclusions of Hoehn and Randall (1987). Not surprisingly in those experiments where provision was guaranteed irrespective of stated WTP (i.e. strong free rider incentive) a larger deviation between stated WTP and true WTP was observed. Such results appear to support the conclusions of Barnett and Yandle (1973) and Garrod and Willis (1990) that free-riding should be addressed via a property rights approach in which respondents receive provision of a good relative to their WTP. However, as these authors point out, such strategies are limited by the characteristics of many environmental public goods[31].

An important caveat to table 2.2 is that all the results presented appertain to OE elicitation formats. As previously discussed, Hoehn and Randall (1987) show that, even in the absence of any free-riding, the lack of an overstatement incentive, imperfect information and time constraints will result in understatement of WTP. Interestingly, in the same paper a case is made for using DC formats as a method of combatting such understatement[32]. Providing that respondents believe that they will pay the DC bid level proffered to them (i.e. conditional upon instrument credibility), then they will only refuse a bid level if it exceeds their formulated value, i.e. there is no theoretical incentive to understate WTP. Indeed, as the authors put it, "in a policy referendum model with individually parametric costs (i.e. DC format), truth telling is the optimal strategy" (Hoehn and Randall, 1987; parentheses added).

Clearly the potential for deliberate understatement of WTP exists although it appears more likely to occur in OE elicitation formats. Accordingly investigation of WTP understatement was made a research priority in our applied work.

iv. Overstatement of WTP

Bateman et al. (1995a) identify five factors which may induce a respondent to overstate WTP in a CV experiment, each of which we discuss further below:

i. Strategic overbidding (all elicitation formats)

ii. The 'good respondent' (all elicitation formats)

iii. Upward rounding (DC formats)

iv. Anchoring (DC formats)

v. Starting point effects (IB formats).

Strategic Overbidding: In an important empirical paper, Bohm (1972) argues that contrary to the prediction of free-riding, respondents may overstate their WTP in hypothetical markets. Such 'strategic overbidding' may occur where respondents feel that their factual individual payment will be related to some sample measure such as mean WTP rather than their own statements. In such a case, if formulated WTP exceeds expected mean WTP, then the respondent may inflate stated WTP (up to the expected mean) in an effort to improve the

[31]Note that a further factor influencing the apparent lack of free-riding in table 2.2 might be the public citizen obligations felt by individuals in respect of environmental goods.

[32]Similar claims are made by Loomis (1987) and Kriström (1990a).

probability of provision. Apart from Bohm's original study there is little empirical evidence regarding the strength of strategic overbidding tendencies. Consequently this was made an objective of our applied work.

'Good' Respondents: Orne (1962) points out that the relationship between analyst and respondent is an interactive process with the respondent seeking clues as to the purpose of the experiment. If this purpose is inadequately conveyed then the respondent may react in two ways, either he will not give the questions due consideration or he will attempt to guess the 'correct' answers, i.e. he will try to be a 'good respondent' and give the answers which he feels that the analyst wants. The problem of low consideration can be assessed by recording and analysing the numbers of respondents who refuse to take part in the survey and the length of interview. The 'good respondent' problem may be exacerbated where the interviewer is held in high esteem by the respondent (Harris et al., 1989) resulting in responses which differ from true willingness to pay. Desvousges et al., (1983) found little evidence of such a bias but it should be noted that this study employed professional interviewers, a potential solution to such problems. Tunstall et al., (1988) further recommend that interviewers follow the wording of the questionnaire exactly and that respondents be presented with a choice of prepared responses so as to minimise over or understatement of true evaluations. Approaches designed to combat hypothetical bias (discussed above) may also be relevant here.

In our own empirical work considerable emphasis has been placed upon minimising such sources of bias at the design stage. Experienced practitioners (including certain of those referred to above) were consulted regarding the construction of questionnaires and execution of surveys. Further details are given in subsequent chapters.

Upward Rounding: Bateman et al., (1993) argue that, in DC formats, respondents may have an incentive to accept bids which are in excess of true WTP if the difference between the two amounts is relatively small. The deviation caused by such an effect will only operate in an upward manner, i.e. respondent will not refuse to pay a bid level which is just below their true WTP. However, provided that the respondents believes in the payment obligation (i.e. he/she does not engage in strategic overbidding) this should be a relatively minor effect and was therefore not made subject to further analysis.

Anchoring: Kahneman et al., (1982) among others have argued that respondents faced with an unfamiliar situation (particularly where the good is also not well described) will interpret the DC bid level to be indicative of the true value of the good in question (Kahneman and Tversky, 1982; Roberts et al., 1985; Kahneman, 1986; Harris et al., 1989). Here the introduction of a specific bid level raises the probability of the respondent accepting that bid. This 'framing' or 'anchoring' effect may arise where a respondent has not previously considered his/her WTP for a resource (which is likely with regard to public or quasi-public goods) and/or is unclear in their own mind about their true valuation. In such cases the proposed bid level may provide the most readily available point of reference onto which the respondent latches. There is no a-priori presumption about the direction of such an anchoring effect. Positioning a bid-vector such that it has more bid levels on the upper tail of the true WTP distribution should lead to anchoring increasing mean WTP. Conversely positioning the bid vector so as to emphasise the lower tail of the distribution should depress mean WTP.

A related problem in DC (and potentially other) formats is the phenomena of "yea-saying" or "nea-saying" whereby the respondent decides ex-ante to answer positively or negatively irrespective of the actual bid presented. Detection of anchoring and related effects is clearly important and was therefore made a research priority.

Starting Point Effects: Several studies have suggested that the use of an initial starting point in iterative bidding (IB) games may significantly influence the final bid, for example, the choice of a low (high) starting point leads to a low (high) mean WTP (see Desvousges et al., 1983; Roberts et al., 1985; Boyle et al., 1985; Navrud, 1989a; Green et al., 1990; Green and Tunstall, 1991). While the use of starting points may reduce non-response and variance commentators argue that such an approach may lead respondents to take cognitive short-cuts to arrive at a decision rather than thinking seriously about their true WTP (Cummings et al., 1986; Mitchell and Carson, 1989; Loomis, 1990). It has also been noted that informing respondents as to the construction costs associated with a proposed environmental change can also affect resultant bids (Cronin and Herzeg, 1982). One approach to this problem is to allow the respondent to choose a bid from a range shown on a payment card. Unfortunately such an approach of necessity produces "anchoring" of bids within the range given on the card with most respondents assuming that such a range contains the "correct" valuation and outliers being effectively ignored (Kahneman and Tversky, 1982; Roberts and Thompson, 1983; Kahneman, 1986; Harris et al., 1989).

Given these concerns an IB format was investigated for evidence of starting point effects.

In summary we can see that elicitation format provides a common theme in our review of both understatement and overstatement incentives. Accordingly our empirical investigation of these incentives was facilitated through an analysis of the effects of employing alternative elicitation formats upon CV responses.

v. Mental Accounting Problems

A further research priority was to assess the extent to which respondents considered income and expenditure constraints in determining their WTP. This problem is addressed in the theory of two-stage budgeting (Deaton and Muellbauer, 1980; Tversky and Kahneman, 1981; Kahneman and Tversky, 1984) where total income is, in the first stage, allocated to various broad categories of expenditure, e.g. housing, food, recreation etc., and then, in the second stage, subdivided amongst the specific items which constitute each category, e.g. forest recreation, water recreation, etc. A potential problem may arise in CV studies if, because of the hypothetical nature of the underlying market, respondents fail to consider all relevant material (Slovic, 1972) such as the particular category budget. Willis and Garrod (1991a) address this point in their CV study of the Yorkshire Dales National Park. Here one subsample is asked, prior to the WTP question, to calculate their "total yearly budget for all environmental issues including those donations and subscriptions that ... (the respondent) might already have made" (ibid). Comparing resultant WTP with that for the remainder of the sample who did not face such a mental account question, the authors report no significant difference at the 1% level. This suggests that mental accounting problems may not be severe. However, it was decided to test such a hypothesis in certain of our empirical work.

vi. Part Whole Bias

Tversky and Kahneman (1981), in considering decision rationality, argue that individuals see groups of goods, rather than specific goods, as the basis for utility maximisation. Extending this, Kahneman and Knetsch (1992a/b) and Quiggin (1991), contend that CV may be fatally flawed by 'part-whole' bias, occurring where an individual's WTP responses fail to distinguish between the specific good which is under analysis (the 'part') and the wider group of goods (the 'whole') into which that specific good falls (see also Kneese, 1984; and Hoevenagel, 1990, 1996). If this were the case then, "when respondents are asked to value some environmental good they may in fact make that valuation on the basis of a much wider range of environmental goods" (Willis and Garrod, 1991a).

The potential for part-whole bias is well documented (e.g. Walbert, 1984; Thaler, 1985; Hoevenagel, 1990, 1996). However, the major recent empirical support for such a criticism is provided by Kahneman and Knetsch (1992a). Here respondents were asked their WTP to maintain the quality of fishing in lakes in Ontario. The authors reported no significant difference between mean WTP for a small number of lakes (about 1% of the total lakes in Ontario) and mean WTP for all lakes in Ontario. Kahneman and Knetsch concluded from this that the WTP statements elicited in CV studies referred to a 'purchase of moral satisfaction' or a 'warm glow of giving' (see Andreoni, 1990), rather than a payment for a good.

An initial criticism of the Kahneman and Knetsch paper was provided by Mitchell (1991) who pointed out that this particular study relied upon both a poor instrument design (using telephone surveys thus relying upon a weak medium of description and dialogue with a high potential for low respondent commitment to the survey); and poor information (a single sentence description was used, arguably providing vague information and thus eliciting a vague valuation, potentially based upon knowledge of the 'whole' rather than the 'part'). These criticisms are expanded upon by Smith (1992) who concludes that it is the question framing itself, rather than some underlying theoretical problem, which results in the reported part-whole phenomena. Indeed, Smith claims that the question framing used by Kahneman and Knetsch "does not satisfy the criteria that Kahneman (see Kahneman and Tversky, 1982) helped to develop in his earlier research on how people interpret valuation questions" (Smith, 1992).

While the criticisms of Mitchell and Smith may be sufficient to discount the particular results of Kahneman and Knetsch (1992a), they are insufficient to prove that part whole bias cannot occur. In the Yorkshire Dales study described previously, Willis and Garrod (1991a) address this problem by comparing respondents stated budgets with their subsequent WTP, i.e. the environmental category budget is taken as a measure of the 'whole' while the 'part' is taken to correspond to WTP for the Dales alone. The authors report a highly significant difference (at the 1% level) between WTP and the overall budget arguing that, even if part-whole bias is occurring such a result indicates that it is insignificant in extent. Bateman et al., (1991) note that mental account and part-whole effects are somewhat similar. Where respondents are asked to state their mental account for a category of goods they are in effect valuing the 'whole'. The empirical evidence for both part-whole and mental account effects is mixed. While Rae (1982), Burness et al. (1983), Tolley and Randall (1983) and Strand and Taraldset (1991) confirm evidence of part-whole effects, Brown and Green (1981), Schulze et al. (1983) and Rahmatian (1987) reject such a hypothesis. In the light of subsequent empirical findings we feel it is important to emphasise the link between part-whole and especially mental accounting problems and the ordering effect observed by Tolly and Randall (1983) and Hoevenagel (1990) where it was noted that a good will elicit a higher WTP response if it is placed at the top of a list of goods to be evaluated, than if it is valued after other goods. If the inclusion of a mental accounting or part-whole question affects subsequent WTP this will violate Rae's (1982) criterion that CV results may only be considered valid if the inclusion of further environmental goods in the questionnaire does not significantly alter WTP values.

Our own view derives from recently completed experimental research into the occurrence of part whole effects in real trades of private goods. These experiments demonstrated that individuals consistently 'overvalue' parts in relation to wholes (Bateman et al., 1996a and forthcoming b). Our conclusion is therefore similar to that concerning reference-dependent utility: that this result is not peculiar to the CV environment (although again poor design may exacerbate it) but rather is a phenomena which calls for an extension to the basic neoclassical microeconomic model of individual behaviour. Accordingly we do not make part-whole issues central to this research preferring instead to refer the reader to the above results for our view of this issue.

vii. Information Bias

Does the quality of information presented to 'service' a hypothetical market affect the responses received? The answer is almost certainly yes. Samples et al. (1985, 1986) compared responses from two experimental groups given varied levels of information regarding an endangered species (the humpback whale) with those responses received from a control group given constant information. It was found that increased information increased mean WTP by between 20-33% however statistical tests showed that while this test was significant at the 20% confidence level it was not significant at the 5% level.

In the study by Mitchell et al. (1988) two groups were given differing information regarding four sites of Special Scientific Interest (SSSI). Again additional information raised mean WTP but did not show this to be a statistically significant increase. A similar weak information bias result is found by Hanley and Munro (1991) in two CV experiments regarding WTP for heathland and woodland preservation. They postulate a threshold effect of information build-up below which no bias is detectable but above which a weakly positive effect is found. A stronger result is provided by Bergstrom et al. (1985) whose study of bids to preserve prime farmland in the USA produced a 1% confidence interval test that additional information had resulted in higher bids. However such a finding is firmly challenged on both empirical and theoretical grounds by Boyle (1989). In an experiment regarding WTP for brown trout fisheries in Wisconsin, Boyle found no significant difference between mean WTP statements for three levels of information although bid variance fell significantly as information increased. Boyle states that "the argument that changes in accurate or true commodity description in the framing of CV questions will change value estimates is unwarranted as a blanket statement".

A less extreme view is adopted by Randall et al. (1983), Carson (1989), Kriström (1990a) and Hanley (1990) who argue that, since individuals do have preferences regarding environmental goods, their provision, distribution and funding, then information will always affect WTP but that this is no different from any other good, priced or not, i.e. this is an expected information input effect. Bateman and Turner (1993) contend that the important issue is therefore to ensure that such information is seen to be true, constant across the sample, and not designed to induce bias towards a particular result; polemic and implicit value judgements being inadmissible. We have attempted to adhere carefully to such guidelines in all the applied research presented subsequently. Given this, the work of Samples et al. (1985, 1986) indicates that inherent information bias should not be an overriding problem.

Procedural and Instrument Related Bias

i. Aggregation and Truncation of Welfare Measures

A particular problem in the estimation of total economic value sums for spatially fixed environmental goods such as forests is that on-site surveys will ignore the non-use values held by non-visitors. We argue that such surveys can only claim to estimate user values and that supplementary random sample remote (off-site) surveys are necessary to estimate non-use values. Such studies (e.g. Brookshire et al., 1982) have shown that when aggregated over the larger non-visitor populations, total non-use value may be significant and may even exceed total use values by a significant factor[33]. Consequently we undertake separate user and non-user surveys in our research.

The aggregation procedure itself can induce bias. An important issue is to define the relevant population at the pre-survey stage and then conduct standard diagnostics to validate the sample collected as being representative of the population[34]. However the connection between the sample and the population is rarely perfect and certain adjustments may be justified, choice of adjustment procedure can however have a major impact upon aggregate estimates. In one experiment Loomis (1987) varied adjustment procedures to produce a 2.25 times difference in the range of aggregate benefit estimates.

A more fundamental question arises is the choice of an appropriate welfare measure for aggregation. If the distribution of WTP bids is non-normal (e.g. Poisson, binominal etc) then the sample mean will have been affected by the major tail (usually upper) of the distribution. However, such skewness of itself does not indicate bias. Only where this is as a result of recognised biases such as strategic overbidding may a problem occur. In such cases truncation of strategic bidders *may* be thought justified. In DC experiments explicit choice of truncation option is a necessary part of calculating mean WTP as this is given by the area under the cumulative probability distribution. This issue is discussed further[35] in our empirical work where a number of truncation options are investigated.

ii. Interviewer Effects

Clearly the character of the interviewer may affect responses either directly by portraying the good in a particularly favourable (or unfavourable) light or indirectly by the impression given to respondents[36]. Evidence of such an effect is mixed, being supported by

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[33]An important point to note here is the criticism that when non-users, unfamiliar with an environmental asset, are asked for their WTP to preserve that asset, they may state some small sum as a token of charitable concern (i.e. the moral satisfaction argument of Kahneman and Knetsch, 1992a). If such sums are accepted as true evaluations, aggregation over the entire non-visitor population (which is likely to be large) may produce considerable sums far in excess of user value. However, until the validity of such amounts can be established, such aggregations should be treated with caution.

[34]See Mitchell and Carson (1989); Hanley (1990). This will be a particular problem for mail surveys where response rates are low as it is likely that responses will be biased towards those with a particular interest in the good and therefore unrepresentative of the general population. Response rates significantly below 40% are common in such surveys. Consequently our applied work adopts face-to-face survey techniques.

[35]See also Bateman et al., 1993, 1995a; Langford and Bateman, 1993.

[36]Clearly 'good' respondent effects (discussed previously) are again relevant here.

the findings of Walsh et al., (1990) and rejected by Desvousges et al., (1983). One obvious approach to this problem is to design clear, unambiguous questionnaires and train interviewers extensively in the art of presenting a neutral survey experience. In our empirical work the 'Total Design Method' advocated by Dilman (1978) proved useful as did the discussion of wider survey issues presented by Converse and Presser (1986).[37]

iii. Payment Vehicle Bias

Rowe et al. (1980) found that WTP to preserve landscape quality was higher when an income tax increase was suggested than when an entrance fee was proposed concluding that respondents viewed fee-paying as a debasement of the experience. Many other studies, for example, Desvousges et al. (1983), Brookshire and Coursey (1987) or more recently Navrud (1989b), have reported a similar effect. Tunstall et al. (1988) feel that efforts should be made to adopt a 'neutral' payment vehicle i.e. one which does not affect WTP.

We have addressed this issue in two ways. Firstly we feel that the temporal unit employed may affect WTP, accordingly we have tested both per visit and per annum vehicles. Secondly, as indicated above, the method of payment may be significant, consequently we have, in various studies, employed a number of differing payment routes including: national and local taxes; user-fees; and charitable donations.

<u>Summary</u>

In the preceding sections we have highlighted a variety of effects and biases which may occur in CV studies. Some of these (e.g. free-riding) fall within economic theory while others, if detected, would question the validity of that theory (e.g. anchoring). In all cases these issues require addressing if we are to minimise bias and thereby maximise the validity of CV welfare estimates. Issues such as those of scenario credibility (hypothetical bias), information and interviewer effects have been addressed by adhering to recognised design recommendations and consultations with acknowledged experts in the field[38]. The issues of understatement and overstatement of WTP were (following Hoehn and Randall, 1987)

[37]Detailed discussion of our approach to survey design and administration is given in Bateman et al. (1992).

[38]In the course of this research the author has discussed design matters with (alphabetically): Kevin Boyle; Richard Carson; Guy Garrod; Colin Green; Michael Hanemann; Nick Hanley; Per-Olov Johannson; Bengt Kriström; John Loomis; Jim Opaluch; Sylvia Tunstall; Kerry Turner; Ken Willis; and many other recognised authorities in the field of CV research.

addressed via analysis of the impacts of altering elicitation method while mental accounting and part-whole problems were examined via the inclusion of specific questions in the survey instrument. Truncation and payment vehicle options were also explicitly addressed while both user and non-user surveys were carried out in order that variations in value between these groups could be considered.

2.2.2.4: Validity

Mitchell and Carson (1989) identify three categories of validity testing for CV studies: Content; Criterion; and Construct, the latter of which may be subdivided into convergent and theoretical validity.

Content Validity

Content validity is a concern over whether the measure estimated (WTP) can be said to accurately and fully correspond to the object under investigation (the construct). Pearce and Turner (1990b) point out both that the true construct (the Hicksian measure) will not be directly observable and that the pure public good nature of certain environmental goods (e.g. clean air) will make the necessarily subjective assessments of content validity extremely difficult to undertake in any structured or replicable manner. Analysts must decide for themselves whether a particular CV questionnaire has asked "the right questions in an appropriate manner" and if the WTP measure is "what respondents would actually pay for a public good if a market for it existed" (Mitchell and Carson, 1989).

In reviewing the literature, Garrod and Willis (1990) conclude that a general improvement in survey questionnaire design has meant that "content validity has not been regarded as too great a problem in recent years". As noted above we have consulted widely in an attempt to maximise the content validity of our questionnaires.

Criterion Validity

One method used to assess the validity of CV estimates is to compare these with the 'true' value (the criterion) of the good in question. For many environmental goods such a test is of course unfeasible and is the reason why CV experimentation is being undertaken. However, experiments such as those by Bishop and Heberlein, discussed previously, do provide us with such a test. These indicate that generally WTP formats will provide more accurate estimates of true behaviour than will WTA approaches. Accordingly, with the one exception of our farmers study (which we justify subsequently), we have adopted WTP formats throughout our empirical work.

Construct Validity

One approach to validity testing is to examine whether the measures produced by CV relate to other measures as predicted by theory. Two variants of this construct validity approach can be identified: theoretical validity, testing whether the CV measure conforms to theoretical expectations; and convergent validity, testing whether the CV measure is correctly correlated with other measures of the good in question.

Tests of theoretical validity have mainly centred upon examination of bid curve functions to see if they conform to theoretical expectations, for example, whether elasticities are correctly signed and have feasible sizes. In an early test of theoretical validity, Knetsch and Davis (1966) estimated bid curves for forest recreation concluding that "the economic consistency and rationality of the responses appeared to be high". A similar approach was adopted by Whittington et al. (1990a) in an examination of WTP for water services in Haiti. Tests of the significance of explanatory variables found them to conform to standard expectations as defined by economic theory.

A further variant of this approach is to examine the explanatory power of bid functions. However the cross sectional nature of CV and similar social survey data tends to produce low R^2 statistics. Hanley (1990) recommends that a minimum R^2 value of 0.2 should be used while Mitchell and Carson (1989) suggest a value of 0.15. However, psychologists are at pains to point out that the very nature of social survey techniques make R^2 statistics of limited use. A much stronger test is to examine specific relationships to see if they conform to theoretical expectations. So, for example, we should expect a significant, positive and marginally diminishing relationship between income and WTP, with a similar relationship between visits to a site and total WTP for it. The significance of coefficients can then be judged via simple 't' statistic tests. Studies which do not establish significant relationships where theory indicates they should exist, must therefore be treated with suspicion[39].

[39]Interestingly the absence of such relationships can be used to test our earlier assertion that non-user WTP valuations for poorly perceived public goods may exhibit small sum charity type responses rather than genuine valuations.

A further theoretical test can be performed where measures of consumer surplus are available. These surplus measures can be compared to the WTP estimates obtained and, by manipulating the Willig equations discussed earlier implied elasticity values can be calculated. Results can then also be compared with theoretical expectations and empirical findings. Similarly Bateman et al., (1994) compare CV results across a variety of goods as a test of internal consistency. Here it is shown that mean WTP varies logically with the availability of substitutes; i.e. reasonableness should not be dismissed as a test (perhaps imperfect) of validity. Finally Smith et al., (1991) propose a variant of convergent testing using CV to measure the demand for actual marketed commodities or programmes. CV results can then be compared with real world outcomes.

Convergent validity may at first seem reminiscent of criterion testing. However, in this context none of the comparative measures can claim to be 'truer' than any other. The most common approach is to compare CV measures with those from revealed preference techniques such as travel cost (TC) or hedonic pricing (HP) methods. Cummings et al. (1986) detail four comparisons of CV with TC and two with property based HP studies, reporting that the value estimates produced by the different approaches were within 60% of each other with some being much closer. Mitchell and Carson (1989) report on a further nine comparisons and concur with this conclusion[40].

A significant problem with such convergent validity testing is that the methods compared are usually measuring different constructs. For example, while CV should in theory be providing estimates of aggregate use plus non-use values, the TC only estimates use value. An important further distinction for site specific environmental goods (e.g. forest recreation compared with the benefits of clean air) is whether the CV study is carried out with just an 'on-site' sample or whether an off-site 'remote' population is also utilised (the first should theoretically hold mainly use values while the second should mainly exhibit non use values). Clearly in the latter case, comparison with TC results is questionable particularly where non-use values are thought to be significant[41]. A further theoretical problem is that, while TC and HP estimates derive from ex-post situations, CV provides ex-ante measures, positing a potential information inconsistency in the comparison of these measures.

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[40]See also Brookshire et al. (1982) and Smith et al. (1986).

[41]Many studies have reported highly significant non-use values, e.g. Walsh et al. (1990) reports existence values as representing over 25% of total value. Other studies have exceeded this estimate (see Mitchell and Carson, 1989).

CV Validity: Conclusion

All of the validity tests reviewed can be criticised. The content validity test is in many respects fundamental, however, its operation cannot (as yet) be formalised and subjective judgement is the underlying operand. Criterion validity as expressed through the comparison of hypothetical with real markets provides perhaps the most substantive test of validity and indeed such tests indicate that WTP format questions can provide valid estimates of true value. Unfortunately the empirical applicability of this test to pure public goods is restricted and results from tests upon private or quasi-public goods can only be extended by inference to give validity to CV estimates of pure public good values. The convergence testing form of construct validity has been subject to considerable practical application. However, we question the degree of comparability between measures obtained by the CV, TC (and HP) on the grounds that they are measuring different underlying theoretical constructs. Construct analysis through theoretical validity testing, does, we feel, provide a defensible test of the theoretical appropriateness of the results obtained and is employed throughout our empirical work.

2.2.3: CONCLUSIONS: THE CONTINGENT VALUATION METHOD

CV is a widely applicable and widely applied monetary evaluation method. It has the potential for application to a wider range of environmental goods than any of the other main monetary valuation techniques. We believe that CV possesses a strong theoretical basis with the unique advantage that it estimates income compensated welfare measures. Furthermore we have demonstrated that this theoretical basis is consistent with many of the empirical results obtained in practice (notably the observed asymmetry of WTP/WTA measures) which rather than being symptomatic of a flaw in the technique, appear to have considerable theoretic justification.

Because of its nature as an expressed-preference survey technique, CV is susceptible to bias and indeed while it is easy to instill bias into responses the task of minimising such bias to an acceptable level is, we recognise, one which requires considerable skill.

We have discussed the major causes of bias and presented a programme for investigating these issues as part of our empirical examination of the value of forest recreation externalities. Validity testing will also be an integral part of this applied work.

2.3: THE TRAVEL COST METHOD

2.3.1: INTRODUCTION

The original idea behind the travel cost method (TC) can be traced back to a letter from Hotelling (first reported in Prewitt, 1949) to the Director of the US National Park Service in which he suggested that the costs incurred by visitors could be used to develop a measure of the recreation value of the sites visited. However, it was Clawson (1959) and Clawson and Knetsch (1966) who first developed empirical models along these lines.

TC is a survey technique. A questionnaire is prepared and administered to a sample of visitors at a site in order to ascertain their place of residence; necessary demographic and attitudinal information; frequency of visit to this and other sites; and trip information such as purposefulness, length, associated costs, etc. From this data, visit costs can be calculated and related, with other relevant factors, to visit frequency so that a demand relationship may be established. In the simplest case this demand function can then be used to estimate the recreation value of the whole site, while in more advanced studies, attempts can be made to develop demand equations for the differing attributes of recreation sites and values evaluated for these individual attributes.

2.3.2: THEORETICAL ISSUES

2.3.2.1: Welfare measures

The demand function estimated by the TC is an uncompensated ordinary demand curve incorporating income effects and the welfare measure obtained from it will be that of Marshallian consumer surplus (shown by the area b + c in the lower panel of figure 2.2).

2.3.2.2: Basis of the method

In essence the TC evaluates the recreational use value for a specific recreation site by relating demand for that site (measured as site visits) to its price (measured as the costs of a visit). A simple TC model can be defined by a 'trip-generation function' (tgf) such as;

$$V = f(C,X) \qquad (2.5)$$

where

V = visits to a site

C = visit costs

$X =$ other socioeconomic variables which significantly explain V.

The literature can be divided into two basic variants of this model according to the particular definition of the dependent variable V. The 'Individual Travel Cost Method' (ITC) simply defines the dependent variable as the number of site visits made by each visitor over a specific period, say one year. The 'Zonal Travel Cost Method' (ZTC) on the other hand, partitions the entire area from which visitors originate into a set of visitor zones and then defines the dependent variable as the visitor rate (i.e., the number of visits made from a particular zone in a period divided by the population of that zone). The ZTC approach redefines the tgf as;

$$V_{hj}/N_h = f\,(C_h, X_h) \qquad (2.6)$$

where

$V_{hj} =$ Visits from zone h to site j

$N_h =$ Population of zone h

$C_h =$ Visit costs from zone h to site j

$X_h =$ Socioeconomic explanatory variables in zone h

The visitor rate, V_{hj}/N_h, is often calculated as visits per 1,000 population in zone h.

The underlying theory of the TC is presented with reference to the zonal variant, and discussion of the differences between this and the individual variant is presented subsequently before consideration of more general issues.

2.3.2.3: The zonal travel cost method (ZTC)

Discussion of the ZTC is illustrated by reference to a constructed example detailed in table 2.3 which estimates the recreation value of a hypothetical site. The method proceeds as follows:

(i) Data on the number of visits made by households in a period (say annually) and their origin is collected via on-site surveys.

Table 2.3: Consumer surplus estimates for the whole recreation experience using the ZTC

	Zone No.	Zonal population (no. of households)[1] (N_h)	No. of household visits to site p.a.[2] (V_{hj})	Average no. of visits per household p.a.[3] (V_{hj}/N_h)	Average travel cost per household visit[4] (£) (C_h)	Consumer surplus per household all visits p.a. (£)	Consumer surplus per household per visit (£)	Total consumer surplus p.a. (£)
Column No.	1	2	3	4	5	6	7	8
	1	10,000	12,500	1.25	0.16	2.60	2.08	26,040
	2	30,000	30,000	1.00	1.00	1.67	1.67	50,100
	3	10,000	7,500	0.75	1.83	0.94	1.25	9,400
	4	5,000	2,500	0.50	2.66	0.42	0.84	2,100
	5	10,000	2,500	0.25	3.50	0.10	0.40	1,000
Total annual consumer surplus of the whole recreational experience = 88,000								

Notes: All figures rounded to 2 decimal places. Trip generating function $V_{hj}/N_h = 1.3\text{-}0.3C_h$.

1. from census records.
2. from survey; annual totals derived by extrapolating from sample data according to available information regarding tourism rates.
3. column 4 = column 3/column 2.
4. either calculated with reference to zonal distance or via survey (see subsequent discussion re. travel costs).

(ii) The area encompassing all visitor origins is subdivided into zones of increasing travel cost (column 1 of table 2.3) and the total population (number of households) in each zone noted (column 2).

(iii) Household visits per zone (column 3) is calculated by allocating sampled household visits to their relevant zone of origin.

(iv) The household average visit rate in each zone (column 4) is calculated by dividing the number of household visits in each zone (column 3) by the zonal population (number of households; column 2). Note that this will often not be a whole number and commonly less than one.

(v) The zonal average cost of a visit (column 5) is calculated with reference to the distance from the trip origin to the site.

(vi) A demand curve is then fitted relating the zonal average price of a trip (travel cost) to the zonal average number of visits per household. This curve estimates demand for the "whole recreation experience" rather than just the time spent on-site. In our hypothetical example this demand is explained purely by visit cost and the curve has the (unlikely) linear form given in equation (2.7).

$$V_{hj}/N_j = 1.3 - 0.3\ C_h \qquad (2.7)$$

where

V_{hj}/N_j = visit rate (average number of visits per household) from each zone

C_h = visit costs from each zone

Figure 2.5 illustrates this particular whole recreation experience demand curve. The estimation of this curve involves the implicit assumption that households in all distance zones react in a similar manner to visit costs. They would all make the same number of trips if faced with the same costs i.e. they are assumed to have identical tastes regarding the site.

(vii) In each zone the household consumer surplus for all visits to the site (column 6) is calculated by integrating the demand curve (equation (2.7)) between the price (cost) of visits actually made from each zone and that price at which the visitor rate would fall to zero (i.e. the vertical intercept of the demand curve at point P in figure 2.5)[42]. Households in zone 3 for example would have a consumer surplus equal to area ABP for all their trips to the site i.e.:

$$\text{Consumer surplus for zone 3} = \int_{C_h=B}^{P} (1.3-0.3\ C_h).dC_h \qquad (2.8)$$

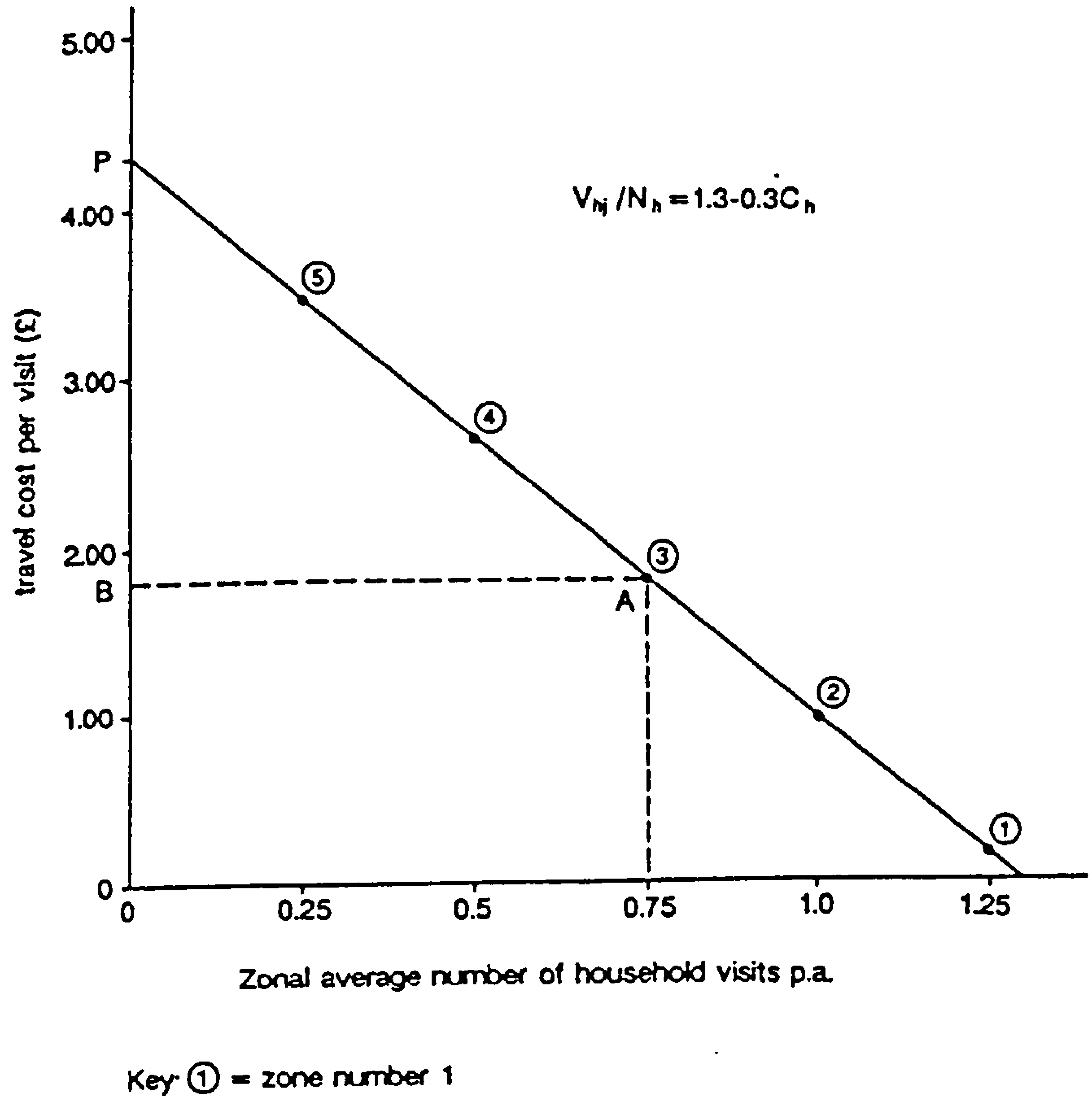
(viii) In order that annual total consumer surplus for the whole recreation experience can be estimated in each zone, total household consumer surplus must firstly be divided by the zonal average number of visits made by each household to obtain the zonal average consumer surplus per household visit (column 7). This can then be multiplied by the zonal average number of visits per annum (column 3) to obtain annual zonal consumer surplus (column 8).

(ix) Cumulating annual zonal consumer surplus (column 8) across all zones gives our estimate of total consumer surplus per annum for the whole recreational experience of visiting the site.

One immediate problem with the above approach is that it yields value estimates for the whole recreational experience of the entire day trip to a (zero-priced) recreation site rather than an evaluation of the site alone. Freeman (1979) points out that the information gathered in a TC survey only in fact defines one point on the demand curve for the on-site recreational experience. Many goods incur a travel cost for their consumption, but their price is set by the market. However the market price of recreation is zero therefore the sum of all visits across all zones represents the demand for on-site recreation with a zero admission price.

[42]Several texts make the simplifying assumption that consumer surplus for the marginal user (here the most remote zone) is zero (Sinden and Worrell, 1979; Hufschmidt et al., 1983). This will typically lead to some underestimate of true consumer surplus.

Figure 2.5: Demand curve for the whole recreation experience



Source: Bateman (1993a)

In estimating consumer surplus for the on-site recreation experience, many earlier texts (e.g. Sinden and Worrell, 1979; Hufschmidt et al., 1983) follow Clawson and Knetsch (1966) and estimate consumer surplus by first assuming that people would react to increases in admission price in the same way as they would react to increases in their travel costs i.e. the demand curve function stays as estimated for the whole experience but each zones travel cost is increased by an incremental admission cost and visits from each zone re-calculated according to the estimated demand curve. Summing visits across all zones at each admission cost maps out the on-site experience demand curve. Integrating under this curve between the initial zero admission price and that admission price at which visits in all zones fall to zero estimates total consumer surplus for the on-site recreational experience. A worked example of such a calculation is given in Bateman (1993a).

The weak link in the Clawson-Knetsch approach to on-site valuation is the need to assume that individuals will react in the same way to admission fees as they do to travel costs[43]. If individuals have different willingness to pay for an environmental good because of the method of payment which is used then it is likely that such an assumption may well be violated.

In practice many TC studied have rejected the Clawson-Knetsch approach to on-site valuation, preferring modification of the whole-experience demand curve. A common approach (adopted in our empirical research) is to ask visitors to evaluate how much of the utility of the whole recreation experience is due to the on-site experience. Typically visitors are asked to allocate percentage points to the on-site and off-site experience. This information can then be used to either reduce travel costs (i.e. evaluate how much of incurred costs can justifiably be said to have been purely related to the on-site experience) or the information can be directly entered into the trip generating function as a separate continuous explanatory variable (for an example see Willis and Garrod, 1991b). In either case the whole-experience demand function will be altered. The resultant curve will not be the same as the on-site demand curve as defined by Clawson and Knetsch above. However, its validity may well be more defensible in that it does not rely upon the previous assumption of travel cost effects perfectly duplicating admission price effects.

2.3.2.4: The individual travel cost method (ITC)

The fundamental difference between the ZTC and ITC is that the latter defines the dependent variable as V_{ij}, the number of visits made per period (annum) by individual i to site j (Brown and Nawas, 1973; Gum and Martin, 1975). We can therefore rewrite the simple tgf of equation (2.5) as its ITC equivalent;

$$V_{ij} = f\ (C_{ij}, X_i) \qquad (2.9)$$

where

V_{ij}	=	number of visits made per year by individual i to site j
C_{ij}	=	visit cost faced by individual i to visit site j
X_i	=	all other factors determining individual i's visits

[43] The problems of vehicle bias, usually discussed with regard to the contingent valuation method (Bateman and Turner, 1992), are pertinent here.

The demand curve produced by this model relates individual's annual visits to the costs of those visits (i.e. there is no requirement to convert from zonal visitor rate to actual visits as in the ZTC). The above tgf relates to the whole recreational experience but may be adjusted to relate the on-site experience via either the Clawson-Knetsch (1966) or Willis and Garrod (1991) approaches outlined previously (the latter being adopted in our work).

The move from a zonal to an individual basis allows the specification of a number of individual-specific explanatory variables, for example, we could respecify our ITC tgf as;

$$V_{ij} = f\,(C_{ij}, E_{ij}, S_i, A_i, Y_i, H_i, N_i, M_i, T_i, Q_j) \qquad (2.10)$$

where

V_{ij} = number of visits made per year by individual i to site j

C_{ij} = individual's total visit cost of visiting site j

E_{ij} = individual i's estimate of the proportion of the day's enjoyment which was contributed by the visit to site j

S_i = individual i's assessment of the availability of substitute sites

A_i = age of individual i

Y_i = income of individual i's household

H_i = size of individual i's household

N_i = size of individual i's party

M_i = dummy variable; whether individual i is a member of an outdoor or environmental organisation

T_i = activity undertaken on site

Q_j = vector of environmental attributes of site

A number of permutations of equation (2.10) are possible. We discuss detailed specification of the cost variable C_{ij} below. However, one approach which we adopt in certain of our later empirical work, is to combine this with the on-site utility variable E_{ij}. So, for example, if an individual assesses that 60% of the days enjoyment was due to the on-site experience then E_{ij} = 0.60 and the utility adjusted cost variable AC_{ij} is 0.6 C_{ij}. Such an approach explicitly addresses the problem of allowing for utility derived from other sites or the journey itself. Other variables may be defined in numerous ways. S_i may either be defined as a binary dummy or as a categorical variable or a continuous variable of the number of substitute sites specified or a vector of distance costs to those sites. Similarly several definitions of M_i and T_i may be used although our experience indicates that simple dummy variables are often effective. The environmental attribute vector Q_j is discussed in further detail subsequently. Further explanatory variables are plausible, for example, Bojö (1985) includes a dummy variable for the mode of transport used which, in an empirical test, he finds statistically significant.

The demand curve for the site will be defined by the $\delta V_{ij}/\delta C_{ij}$ relationship as illustrated in figure 2.6. Integrating under this curve gives us our ITC estimate of consumer surplus per individual. Our estimate of consumer surplus for the site is then obtained by multiplying by the number of individuals visiting the site annually[44], ie;

$$\text{Total consumer surplus} = N_j . \int f(C_{ij}, X_i) . \, dC_{ij} \qquad (2.11)$$

where

N_j = number of individual visits to site j per year

(C_{ij}, X_i) = defined as per equation (2.9)

2.3.3: METHODOLOGICAL ISSUES

Here we review the principle methodological issues arising in the application of the TC and show how we have addressed these in our practical studies.

2.3.3.1: The central assumption

The underlying assumption that visit costs can in some way be taken as an indication of recreational value requires qualification. In an early study Gibson (1978) notes that where individuals have changed their place of residency so as to be close to a site (e.g. moving into a country area to be near a recreation site) then the price of a trip becomes endogenous and the central assumption is violated[45]. In such a case the estimated demand curve will lie below the true demand curve and consumer surplus will be underestimated.

Very few empirical studies have taken account of this potentially important criticism.

[44]Care has to be taken in the aggregation procedure as data may well have been gathered in the form of household or party visits whereas total annual visitor data is usually held as numbers of individuals. Household data must be converted to individual visit data to avoid underestimation (or, on occasion, double counting).

[45]This problem is also noted in earlier studies, e.g. H.M. Treasury (1972).

However in a recent study, Parson (1991) argues that the endogeneity may be eliminated using an instrumental variables approach (place of work, job characteristics, etc). A simple variant of this would be to include a survey question regarding the importance of proximity to the recreation site in deciding place of residency. A dummy variable could then be used to split up responses with significance tests determining the importance of this factor.

A related problem arises where the on-site time is not the only or even major objective of the trip. Cheshire and Stabler (1976) define three categories of visitor; the 'pure visitor' who is strongly site orientated; 'transit visitors' who make multi-visit trips; and 'meanderers' who gain utility primarily from the journey itself[46]. While pure visitors pose no theoretical problem, transit visitors pose the problem of how journey costs are to be allocated amongst the sites visited. This problem also applies to meanderers where the on-site time is by definition only a side issue in the trip decision and where travel time in particular may not represent a true opportunity cost, i.e. the utility of travel time may range from negative to positive across these visitor categories. These latter issues are discussed below in the context of time costs.

2.3.3.2: Calculating visit costs

Total visit costs can be defined as the sum of money expenditure on travel (e.g. petrol costs, etc), the opportunity cost of travel time and the opportunity cost of on-site time (usually zero). More exactly we can define (for an ITC study)[47];

$$C_{ij} = PTC_{ij}.D_{ij} + PTT_{ij}.TT_{ij} + PST_{ij}.ST_{ij} \qquad (2.12)$$

where

C_{ij} = Total cost to individual i of visiting site j

PTC_{ij} = Money expenditure on travel per mile/km

D_{ij} = Distance travelled by individual i to site j

PTT_{ij} = Individual i's opportunity cost per hour of travel time to site j

TT_{ij} = Individual i's journey time to site j (hours)

PST_{ij} = Individual i's opportunity cost per hour of on-site time at site j

[46]In a related study, Christensen et al. (1983) discuss the problem of disaggregating holiday from single visit costs.

[47]For a ZTC equivalent see Bateman (1993a).

ST_{ij} = Individual i's length of on-site time at site j (hours).

One basic problem in evaluating C_{ij} is that PTC_{ij} is unlikely to be a constant for all segments of the journey. Rather the variable quality of roads used in a journey will lead to varying per mile travel expenditure rates. Travel time will also vary in a similar manner. Both of these issues are considered below.

i. Travel Costs

In calculating travel costs, Bojö (1985) simply multiplied household size by the economy class rail fare. However, such a simple approach is less applicable to car travel, where three cost calculation options exist;

(1) Petrol costs only (marginal costs)

(2) Full car costs; petrol, insurance, maintenance costs, etc.

(3) Perceived costs as estimated by respondents.

Clearly using option (2) will raise visit costs above that of (1) and ultimately increase consumer surplus estimates. Hanley and Common (1987) apply both options to the same forest recreation data finding that option (2) gave a consumer surplus estimate more than twice as large as option (1).

Willis and Benson (1988) obtained a similar result in a study of visitors to wildlife areas in Yorkshire. Results for one of the sites studies are given in table 2.4 showing that the move from defining travel costs as petrol only to a definition of petrol plus standing charges made no significant difference to the explanatory power of the model (same functional form retained); and only a minor impact upon the cost coefficient (highly significant in both cases) i.e. both assumptions had equal statistical validity. However this translated through into a major increase in consumer surplus per visitor (over 70% bigger for the full cost assumption) and thereby to total site consumer surplus.

Table 2.4: Impact upon estimated consumer surplus (CS) of alternative travel cost specifications

Travel cost Specification	Travel cost coefficient	Model R^2	CS/visitor £	Visitors p.a.	Total CS estimate (£)
Petrol only	-2.667 (6.73)	0.83	0.59	15,235	9,001
Petrol plus standing charges	-2.605 (6.49)	0.83	1.02	15,235	15,574

Notes : Case study : Wildlife visitors to Skipwith Common, Yorkshire
Method : ZTC
Functional form : Double log throughout
CS/visitor rounded to nearest penny
Figures in brackets are t-statistics

Source: Abstracted from Willis and Benson (1988).

Price (1983) and Christensen (1983) argue that the correct cost measure is that which visitors perceive as relevant to the visit. It may well be that visitors are poor at perceiving daily insurance and maintenance cost equivalents or that they see these as sunk costs which do not enter the tgf, i.e. they only consider the marginal cost of a visit, equating this with marginal utility.

As a result of this apparent conflict we adopt a sensitivity analysis approach in our empirical work, testing all three of the above cost definitions.

ii. Time Costs

As indicated in equation (2.12), time enters the visit cost function through the travel time and on-site time variables. However, theoretical analysis (McConnell, 1975; Freeman, 1979; Wilman, 1980; Johannson, 1987; and Bateman, 1993a/b shows that the relevant opportunity costs per hour need not be the same for these two items. Furthermore, determination of these opportunity costs raises considerable problems.

Travel time values are particularly difficult to analyse in that, as noted previously, we have no definite a-priori notion about whether travel time utility is positive or negative. If travel time has positive utility (i.e. individuals enjoy the travel as part of their recreational experience, e.g. 'meanderers' as previously defined) then using some general travel time cost figure to price this will overestimate the consumer surplus of a visit. Bojö (1985) does not include a travel time cost (i.e. implicitly he gives such time an opportunity cost of zero) on the grounds that 80% of survey respondents expressed a positive utility for travel time to the site under analysis. This approach assumes that ignoring residual travel time costs only leads to a minor underestimate of the true consumer surplus.[48]

However, the Bojö approach is far from standard. Indeed static optimisation of any conventional utility function (subject to income and time constraints) would indicate that the marginal rate of substitution between labour and leisure (i.e. the value of recreational travel time) is equal to the wage rate. However, when individuals are not able to completely vary the number of hours worked the substitution of time for money becomes constrained and the direct relation between the value of time and the wage rate breaks down (Johnson, 1966; McConnell, 1975).

Early applied investigations of the actual relationship of wages to travel time were undertaken by Cesario (1976) and Cesario and Knetsch (1970; 1976). These papers examined commuters choice of transport to and from work (and relevant costs) to estimate an implicit value of travel time. Cesario concluded "that, on the basis of evidence collected to date, the value of time with respect to nonwork travel is between one quarter and one half of the (individuals) wage rate" (Cesario, 1976), and subsequently used a value of one-third the wage rate to price travel time. An alternative approach is that of Nelson (1977) who calculated a marginal implicit price of proximity to the central business district with housing data for Washington DC, from which he derived a value of time which, when related to wage rates, falls within the Cesario range. However, as he recognised at the time, Cesario's analysis only considers commuter time and there is no necessary reason why the marginal utility obtained should be applicable to recreation travel time.

Common (1973) and McConnell and Strand (1981) used an iterative process whereby successive time values are substituted into the tgf the final choice being determined where the explanatory power (R^2) of the model is maximised. Desvousges et al. (1983) applied the value of time results of Cesario (1976), McConnell and Strand (1981) and a full wage rate assumption to an ITC model of individual visitation patterns at 23 water recreation sites in

[48]Johansson (1987) points out that, if time costs are ignored then "the estimated curve will be located inside and be less steep than the 'true' one, except possibly for those living very close to the recreation site, since the underestimation of costs increases in relation to distance from the visitors zone of origin".

the USA. Testing at the 10% confidence level, Desvousges et al. (1983) rejected the McConnell and Strand (1981) approach, while both the Cesario (1976) and full wage assumptions performed equally well, both being rejected in roughly 7 of the 23 cases. On the basis of these results Smith and Desvousges (1986) concluded that "for practical purposes, there is no clearcut alternative to our using the full wage rate as a measure of the opportunity cost. Even though it may overstate the opportunity costs ... none of the simple adaptations are superior".

Similar results are obtained in a completely different cultural setting by Whittington et al. (1990b) in a study of the value of time spent collecting water in Kenya. Here two separate approaches are employed, both of which indicate a value of time approximately equivalent to the wage rate for unskilled labour. However, activities such as collecting water are qualitatively different from those associated with recreation. In their TC study of UK forest recreation, Benson and Willis (1992) employ three value of time assumptions, justified as follows:

i) 0%; this assumes that visitors would not benefit from some alternative recreation activity.

ii) 25%; the UK Department of Transport's value of non-working time used in CBA assessments of road proposals up to 1987.

iii) 43%; the value of time used by the UK Department of Transport following their review of non-work time in 1987 (Department of Transport, 1987).

The 0% figure initially appears difficult to defend. However, if visitors cannot vary or extend their work hours (i.e. there are no forgone wage costs) and there are few competing recreational opportunities then the opportunity cost of time well be low. The two Department of Transport figures are both based upon Cesario-type analyses of which the latter (43%) appears the more rigorous.

While the Cesario approach is, on the surface, theoretically and practically appealing, a deeper analysis of the complexities of the work/leisure relationship highlights some important problems. In a thorough analysis, Bockstael et al. (1987) note two major issues: (i) wage rate may vary with work hours, for example, a second job may pay a lower rate than does a first; (ii) individuals face uneven time constraints, i.e. they may be restricted to work specific hours in particular jobs. As a result the wage rate may be an appropriate measure of time costs for those (at interior solutions) who can fully vary their work hours, but it will be inappropriate for those who cannot (at corner solutions).

While Bockstael et al. provide a theoretically plausible approach to the valuation problem by incorporating time and income constraints into a utility function, the empirical application of such a technique is problematic. In particular the data requirements of such a model, including information regarding each individuals time constraints, are highly exacting. For these reasons such complex approaches have not been widely adopted and no published UK study has attempted such an analysis.

Shaw (1992) provides a number of suggestions regarding how the value of time problem might be addressed in a practical study. One suggestion is to use CV-type questions to elicit WTP for recreation time[49] while another is to accept that there is likely to be some rather unclear link with wage rate and to therefore use a sensitivity analysis approach utilizing a wide variety of wage fractions.

Turning to consider the unit value of on-site time, if the length of time spent on-site were a constant for all visits to a particular site, then such costs could effectively be ignored as they would imply only an increase in absolute visit costs but not in marginal relationships (McConnell, 1992; Bateman, 1993a). Furthermore, in an empirical analysis, Bojö (1985) finds no evidence to refute an assumption of constant on-site time costs while Bockstael et al. (1987) omit on-site time from their empirical analysis because of its potentially ambiguous effect upon demand arising from its entry within both the utility function and constraints.

iii. Summary: treatment of travel and time costs

The treatment of travel and time costs within the tgf is one of the most crucial issues in operationalising the TC. The approach we have adopted in this study is as follows:

a) Measurement: One fundamental issue concerns the measurement of linear and temporal distance. We believe that our use of GIS manipulated digital road networks (incorporating road length quality and average travel time by individual road section) in certain of our TC studies, considerably enhances their accuracy of measurement compared to that in most other published studies.

[49]We employ a similar approach in our TCM study of the Norfolk Broads (unpublished). Here respondents were asked WTP to reduce travel time. However, many gave a zero response indicating that the journey contributed positively to trip utility. Further direct questions confirmed this finding.

b) Travel costs: Following the above review we adopt three definitions of monetary travel costs: petrol only; petrol plus standing charges (insurance, depreciation, etc); respondents perceived travel cost.

c) Time costs: We adopt the suggestion of Shaw (1992) and perform a wage rate sensitivity analysis upon travel time. Four wage rate values are employed; 0% (following the argument of Benson and Willis, 1992); 43% (the UK Department of Transport's value of time); 100% (following the empirical findings of Smith and Desvousges, 1986); and that variable wage rate percentage which provides a best fit of the data (our preferred option). We recognise the limitations of such an approach and that the labour supply method of Bockstael et al., (1987) is theoretically superior. However, such an analysis is both complex and demanding in terms of data requirements. Given limited resources our approach should provide a reasonable approximation while yielding an analysis which is more rigorous than other contemporary UK studies. In line with such studies, we have omitted on-site time from the cost function (although such data was collected and analysed), following the argument that this may not significantly affect consumer surplus[50].

d) Total costs: Given that travel and time costs are both a function of distance, their independent inclusion within the tgf is likely to create significant problems of multicollinearity. Accordingly (and for additional reasons reviewed subsequently) we follow Brown and Nawas (1973) and Gum and Martin (1975) in using the ITC which we adapt following Cesario and Knetsch (1970) by adding together travel and time costs to produce total visit costs.

In relevant studies we then multiply this by the respondents stated proportion of the total days enjoyment attributable to the site in question thereby allowing for that proportion of the days utility derived from other sites and the journey itself. This adjusted visit cost is then entered as a single explanatory variable within the tgf.

2.3.3.3: Site attributes (environmental quality and multicollinearity)

The trip generating function described in equation (2.10) highlights several independent variables as explanatory of visits, one of which is the site environmental quality variable, Q_j. In a simple single stage analysis the entire function is estimated as one with

[50]Following the analysis of McConnell (1992) who shows how on-site time may, in certain circumstances, be a significant factor (and proposes a solution to its treatment), we intend to incorporate this into future studies.

conventional significance and other statistical testing being carried out. While this is a common approach it is, strictly speaking, only universally valid for quantifiably unidimensional sites, that is, sites which possess only a single environmental quality attribute which can be measured in a quantitative manner. The reason for this is that, where sites possess multiple attributes, these attributes should enter the tgf as separate variables. However these attributes may themselves be highly correlated, i.e. a potential multicollinearity or 'suppressor variables' (Conger, 1974) problem exists making single stage OLS estimators invalid.

In reality recreation sites very often provide multi-attribute services. For example Vaughan and Russell (1982) include the explanatory variable Q_{kj}, the level of quality characteristic k at site j where k may be one or more. If k>1 then there may be multiple environmental quality factors significantly influencing visit rate. These factors may well be collinear, for example, forests which are large may also have many access routes, but both of these factors may be positively related to visits. A worked example of the suppressor variable problem in TC studies is given in Bateman (1993b).

In reality a number of possible outcomes may arise from a suppressor variable problem. Coefficients may alter radically, even changing signs. Furthermore the significance of parameters becomes disturbed and may even spuriously increase (see Langford, 1992). However, despite the potentially serious nature of this problem, no single definitive solution has yet been found[51]. Clearly a first step is to test for the presence of such a problem by calculation of correlation tables. A further test is to estimate single explanatory variable regression models for significant variables and examine how coefficients and significance levels alter in subsequent multiple regression models. If such a problem is confirmed one proposed course is to replace all site attribute variables with a single index of site attractiveness, thus removing collinearity (Talheim, 1978; Ravenscraft and Dwyer, 1978). However, such an index cannot be adequately set up without full knowledge of the functional relationship between demand and site attributes. As this relationship is dictated by individual preference for different attributes, the creation of a truly representative index is infeasible. Ideally we would wish to respecify the individual's utility function in terms of the attributes

[51]Interestingly Maddala (1988) comments that "some solutions often suggested for the multicollinearity problem can actually lead us on a wrong track. The suggested cures are sometimes worse than the disease" (p.224).

of sites. Morey (1981, 1984, 1985) adopts various functional forms for the utility function which include site attributes and levels of use. By assuming budget constrained utility maximisation we can obtain estimating equations from which parameters (including those for site attributes) can be estimated. However, the need to specify the form of the utility function constitutes a weak link in this approach. A further approach is to use a two stage generalised least squares approach[52] (the generalised travel cost method). Such an approach is adopted by Smith and Desvousges (1986) in their study of lakeside recreation in the US. Here the authors postulate a 'true' trip generating function containing both socioeconomic and various site attribute variables, the latter being highly collinear. The authors employ a two stage approach, the first stage of which consists of omitting all potentially collinear site attribute variables and estimating a tgf containing the remaining socioeconomic variables.

The resultant coefficients are then regressed against the remaining site attribute variables in the second stage to produce generalised demand functions for those attributes. In effect then the tgf therefore relates visits to socioeconomic variables and site attributes, the latter being expressed as subfunctions of the socioeconomic variables.

In order to calculate the relationship (partial derivative) between visits and a particular site attribute, information regarding the values of the socioeconomic variables is required. Smith and Desvousges (1986) address this problem by using mean values of these variables within the subfunctions of the tgf.

By adopting such an approach Smith and Desvousges (1986) produce estimates of the impact of individual site attributes upon visits, i.e. they estimate attribute demand functions. This provides an important extra facility to the TC in that such demand estimates allow the analyst to investigate which attributes contribute most to overall site demand and thus to welfare. In effect such functions allow us to specify which attribute, or combination of attributes, individuals most enjoy at a recreation site and thus facilitate the optimum planning of site development and creation. Further consideration of this approach and a worked example is given in Bateman (1993b).

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[52]An alternative two stage approach is to employ factor analysis or principal components analysis approaches (Goddard and Kirby, 1976; Johnston, 1978). These approaches rely on the formation of combination variables made up of weighted combinations of the explanatory variables. While this weighting can be adjusted to maximise the statistical significance of the model, the resulting combination variables often defy practical interpretation thereby greatly reducing the usefulness of the model in any predictive economic analysis. Such an approach has been used more in the context of urban planning literature and is not pursued here.

While the Smith and Desvousges approach is interesting it is but one method of addressing a problem which, to date, has no definitive solution[53]. Furthermore, it has several drawbacks notably its complexity, the difficulty of determining an appropriate measure for environmental attributes, and the relatively low power of resultant models[54]. A simpler approach is to confine analysis to similar sites. In effect this is the strategy adopted by Willis and Benson in their TC studies of UK forest recreation. As an initial part of this study a cluster analysis was undertaken grouping forests into sets of similar attributes (Benson and Willis, 1990; discussed in subsequent chapters). Our task is made yet simpler by the fact that we are ultimately concerned with potential rather than actual forests. Therefore, by conducting our field work in forests which have those attributes which we are interested in (i.e. recreational facilities) and conducting tests of the transferability of our estimates to similar forests in other locations we can, to some extent, claim to have controlled for (if not solved) the suppressor variable problem. Such a strategy underpins much of our applied valuation work as discussed in subsequent chapters.

2.3.3.4: Weighted observations (heteroskedasticity and sampling bias)

The observations used for estimating the demand curve in ZTC analyses represent a series of samples of varying size from zones which themselves will often have varying populations. As such these observations may have varying degrees of precision; they may have non-constant variance (i.e. subject to heteroskedasticity). This means that (Maddala, 1988): the least squares estimators are unbiased but inefficient and estimates of the variances are biased thus invalidating significance tests.

A common approach to heteroskedasticity problems is to transform the data by logs[55], however Snedecor and Cochran (1976) state that a general approach "is to weight each estimate inversely as its variance" i.e. a weighted least squares (WLS) approach in which observations of low precision are given low weight. Such an approach is adopted by Bowes and Loomis (1980) who suggest that observations be weighted directly by zonal population

[53]The multi-level modelling approach (Jones, 1991; Langford, Bateman and Langford, 1996) appears particularly promising here and we are currently employing such an approach in our ongoing evaluation work.

[54]In their study of 22 US lakes Smith and Desvousges report R^2 values between 0.02 and 0.54 with a simple mean of 0.22.

[55]Maddala (1988) outlines a variety of possible approaches (p.161 et sec.).

(i.e. large populations should produce more precise observations). However, Christensen and Price (1982) point out that heteroskedasticity arises not only because of differing zonal populations but also from differing zonal sample sizes which in turn derive from differences in visitation rate across zones (an individual's visitation rate is likely to be higher in zones nearer to the site). Following this argument, in a subsequent paper, Price et al. (1986) weight demand curve observations by zone population/visit rate.

Lucas (1963) shows that a weighting approach may also be appropriate where sampling bias arises in the presence of a correlation between length of stay and travel cost e.g. individuals who travel further (higher travel costs) stay at sites for shorter periods than those who come from nearby and thus the former group are less likely to be sampled. Lucas argues that, in such cases, weighting individual travel costs by the reciprocal of the length of stay will correct this bias. Price et al. (1986) present various permutations of a forest recreation model, one of which combines both their own heteroskedasticity weighting and Lucas's sampling bias weighting.

Potential heteroskedasticity problems appear more likely to occur in ZTC than ITC models. Combining such models with logarithmic (as well as other) functional forms and explicit heteroskedasticity testing, appears to us a sensible approach to this problem and one which we investigate in our applied work.

2.3.3.5: Substitute sites

Substitute sites should impact upon visit demand in three ways: the visit price of the substitute sites; their entrance fees; and environmental quality at substitute sites. In practice such variables are rarely included in estimated forms (e.g. Smith and Desvousges, 1986), the major practical difficulty being the high data costs involved. In effect a TC survey would have to be performed at all significant substitute sites in order to provide the full data requirement (Bockstael et al., 1991).

The presence of substitute sites deflates recorded demand. The further away that people live from a site the higher the probability that there are substitute sites closer to them than the site in question i.e. the observed trip demand curve is depressed below the true demand curve at higher travel costs.

By concentrating upon site loss (i.e. the sites 'contribution value' to the total recreation value of all sites) rather than conventional TC site value, Price (1975, 1978) and Connelly and

Price (1991) show that, in fact, the presence of substitute sites leads the TC to either systematically over or underestimate true consumer surplus dependent upon the spatial relationship between sites and population centres. Assuming that population is randomly distributed, Price et al. argue that if recreation sites are clustered then the loss of one site will, on average, make little difference to the general proximity of population to sites i.e. the conventional TC site value will overestimate the value of site loss. Conversely if sites are systematically-spaced (particularly relevant for man-made recreation areas) then the loss of one site will induce a major site-proximity change for the nearby population and the TC value will underestimate the true value of site loss. Only where sites (as well as population) are randomly distributed will these over and underestimations on average cancel out and the TC value accurately represent the true value of site loss. However, in a simulated model test of this hypothesis, Connelly and Price (1991) found that curve fitting errors could more than outweigh the impacts of substitute sites (see discussion of functional form).

A number of solutions to the substitute sites problem have been put forward. Price (1979a) addresses the problem "by the simple expedient of basing visit rates, not on visits per year per 1000 population, but on visits per year per 1000 population for whom this is the nearest facility of its type". However, this is at best a partial, lower-boundary approach, ignoring distant visitors who presumably value their visits highly.

Burt and Brewer (1971) use their subjective judgement to identify presumed substitute sites and enter the distances from respondents' homes to these sites as explanatory variables in the tgf. Such an approach is admittedly subjective however a more fundamental criticism is that it implicitly assumes homogeneity of sites, an improbable assumption. Greig (1977) imposes a predetermined, utility-based model linking visits to site characteristics. Such an approach may also be criticised both for lack of adequate prior information regarding the appropriate utility relationship and the need to define site characteristics. A hybrid of the Greig/Burt and Brewer approach could theoretically be constructed if data were available on actual visits to substitute sites. Given such data we could run a Burt and Brewer substitute-distance model and compare predicted visitor rates under the homogeneity assumption with recorded actual visit rates. Differences between actual and predicted figures could then be used to provide information regarding the utility characteristics of the sites.

Connelly and Price (1991) suggest a fundamental change to the Clawson procedure by asking visitors hypothetical questions regarding their expected visit pattern if the site in question was to be closed. These responses could then be fed into the TC model as proxy variables regarding substitute sites. An interesting attempt to formulate such a substitute availability index is given in Bojö (1985)[56].

Here the degree of substitutability of a site was measured by questioning respondents as to their preferences for substitute sites. Unfortunately his field experiment found that the majority of respondents all named one and the same site as their preferred substitute and it became impossible to operationalise the index.

In a recent literature review, Bateman (1993a) concludes that the lack of adequate consideration of substitute sites remains a weakness in many TC models. Given the pervasiveness of this problem and the apparent lack of a readily available solution, this issue was not explicitly addressed in this study. We acknowledge this as a problem which we tackle in recent research not presented in this study (Bateman and Lovett, 1996; Bateman et al., 1996b).

2.3.3.6: Congestion

A site becomes congested when the number of visitors at a site rises to the point where the supply of the characteristics of that site becomes restricted (i.e. the presence of marginal users diminishes the utility of other users). In extreme cases congestion will invalidate a TC study as the observed visits correspond not to the standard demand constrained system but to the intersect of an undefined demand curve with an unknown supply curve i.e. the system becomes under-identified.

While Vaux and Williams (1977) feel that this problem is not of "overriding importance", in an early experiment Stankey (1972) records that 82% of his sample felt that "solitude - not seeing many other people except those in your own party" was desirable. Johannson (1987) states that site visitor numbers (X_v) may be a separate argument in the individual's utility function. Furthermore, Bateman (1993a) points out that this argument may be complex in that, where X_v is very low (or zero), utility may be impaired as people feel lonely or intimidated at the site (this will obviously not be so for all individuals). As X_v increases to a small number so utility may rise with the possibility of social interaction. However, as X_v becomes large utility may again decline as congestion sets in. The visit

[56]See discussion in Bateman (1993a).

decision may therefore well be dependent upon individual's expectations of X_v. Such differences between expected and actual X_v might also prove significant in CV studies.

The presence of congestion (or excess demand) means that the observed demand curve is an underestimate of true demand. The classic treatment of this problem is presented by Fisher and Krutilla (1972) and summarised in Bateman (1993b). The presence of congestion depresses demand for the site such that the TC estimated demand curve lies below that for the uncongested site. Christensen (1983) suggests that the true demand curve may be revealed by placing successive quantity restrictions upon visitors and re-estimating the TC demand curve at each iteration. However, it is difficult to envisage how such a quantity restriction could be placed upon visitors while still maintaining zero priced visits. Accordingly, in practice, simpler approaches have been adopted to the quantification of congestion effects.

Smith and Desvousges (1986) attempt to account for potential site congestion by eliciting the opinions of recreation site managers as to the level of site congestion. On the basis of received responses they concluded that congestion was not a significant factor at the sites studied and omitted it from further consideration. Freeman (1979) lists several references to the use of non-visitor samples drawn from the regional population of travel cost zones to examine how many present non-users would use the site if environmental quality were to be improved (Burt and Brewer, 1971; Brown and Nawas, 1973; Gum and Martin, 1975) and such an approach could be extended to the analysis of congestion. However, through a series of papers, Price (1979, 1980, 1981, 1983) concludes that, in cases of severe congestion, expressed rather than revealed preference techniques may be more appropriate. Our own approach has been to assess congestion both subjectively and through inspection of the availability of car-parking during the survey period. This simple approach appears to have been adequate in our empirical studies.

2.3.3.7: Functional form

Analysts are faced with a variety of functional forms under which the tgf can be specified (typically linear, quadratic, semi-log and log-log). None of these has strong theoretical ascendancy over the others. However specification of a linear form exhibits a first derivative which will be a constant and is therefore theoretically problematic. Log forms may be useful for elasticity estimates and have the advantage of avoiding negative values for the dependent variable[57]. However, the double log form may also be criticised on theoretical grounds as its asymptotic properties imply infinite visits at zero costs, an attribute which is particularly unlikely for on-site experience demand curves (see Everett, 1979).

An altered functional form (even if it has similar explanatory power) can have a highly significant impact upon the demand curve and resultant consumer surplus estimates. In a ZTC study of recreational fishing in Grafham Reservoir (UK), Smith and Kavanagh (1969) found that both semi log (dependent variable) and double log functions fitted the data very well (R^2 = 0.91 and 0.97 respectively)[58]. However when the resultant demand curves were examined it was found that, at a zero admission price, while the semi log form predicted 54,000 annual visits the double log form predicted over 1,052,000 annual visits with obvious consequences for consumer surplus estimates. Subsequent re-estimation made little difference to this divergence.

In theory the most appropriate functional form may be evaluated by examining relative degrees of explanation. However, R^2 tests are strictly non-comparable where the dependent variable changes. A more valid test is to compare visitor rates predicted by the model with actual observed visitor rates using either a large sample, Wilcoxon signed rank test[59] or a Mann Whitney U test[60] as appropriate[61].

Because of its large potential for disturbing consumer surplus estimates, we see the functional form issue as one of the most serious problems affecting the TC (as pointed out it may potentially have far more impact than substitute site or congestion effects). Consequently we have made this a priority issue in our applied research. We investigate a variety of functional forms and estimation procedures (see below) as well as performing tests of actual versus predicted arrivals.

2.3.3.8: Estimation procedure

Pearce and Markandya (1989) point out that a truncation bias may be introduced where least squares estimation techniques are employed. The normal error distribution inherent in

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[57]See, for example: Ziemer et al. (1980); Vaughan et al. (1982); Desvousges et al. (1983); Smith and Desvousges (1986); Hanley (1989); and Benson and Willis (1990).

[58]See subsequent comments re. R^2 figures for ZTC studies.

[59]Wilcoxon (1945), see Mendenhall et al. (1986), p.806.

[60]Mann and Whitney (1947), see Kazmier and Pohl (1987), p.496.

[61]Box-Cox approaches to fitting functional forms are discussed with reference to the hedonic pricing method in Bateman (1993b).

this technique allows the estimation of continuous and negative visitor rates rather than its discrete non-negative reality. This problem will not be fully solved by simply resorting to log dependent variable functional forms. OLS estimation is, strictly speaking, inappropriate for TC models and should be replaced by procedures such as maximum likelihood (ML) estimation.

Empirical studies come to differing conclusions regarding the extent of variance between OLS (truncated) and ML (non-truncated) estimates of consumer surplus. In a TC study of deer hunting quality, Balkan and Kahn (1988) found that OLS and ML estimates differed by relatively small amounts. On the other hand Garrod and Willis (1991) found that, while some forest recreation sites produced relatively similar OLS and ML consumer surplus estimates, other sites produced very different results (one site differing by a factor of nearly 20). Smith and Desvousges (1986) compared OLS and ML estimated TC models for 33 water recreation sites. Estimates of mean variance obtained under both approaches were compared, and highly significant differences were taken as indicating high truncation effects. Using this approach 11 of the 33 sites were identified as highly truncated and were omitted from further investigations.

Other work fundamentally questions the appropriateness of switching to ML estimation as a counter to truncation bias. Both Kling (1987, 1988) and Smith (1988) suggest that, while ML techniques are theoretically more appropriate, OLS techniques (once trimmed to remove predicted negative visits) may actually produce more accurate consumer surplus estimates. Given this debate we have employed both OLS and ML estimation techniques in various of our TC studies.

2.3.3.9: Zonal v individual TC studies

Throughout this chapter we have referred to both the zonal and individual variants of the TC and, as Hanley (1990) points out "there is no consensus in the literature as to which option is preferable on theoretical grounds". However when both approaches are applied to the same data the two methods are capable of producing disturbingly different results. Table 2.5 illustrates this point with regard to a joint ZTC/ITC study of six UK forest sites. Using the same estimation procedure (OLS) and cost definition (full running costs) throughout, estimates of consumer surplus produced by the ZTC ranged between almost 40% less to almost five times larger than those produced by the ITC. As all cost coefficients produced by both methods are statistically significant this points towards some serious methodological problems for one or both of these approaches.

Table 2.5: ZTC/ITC consumer surplus estimates for six UK forests

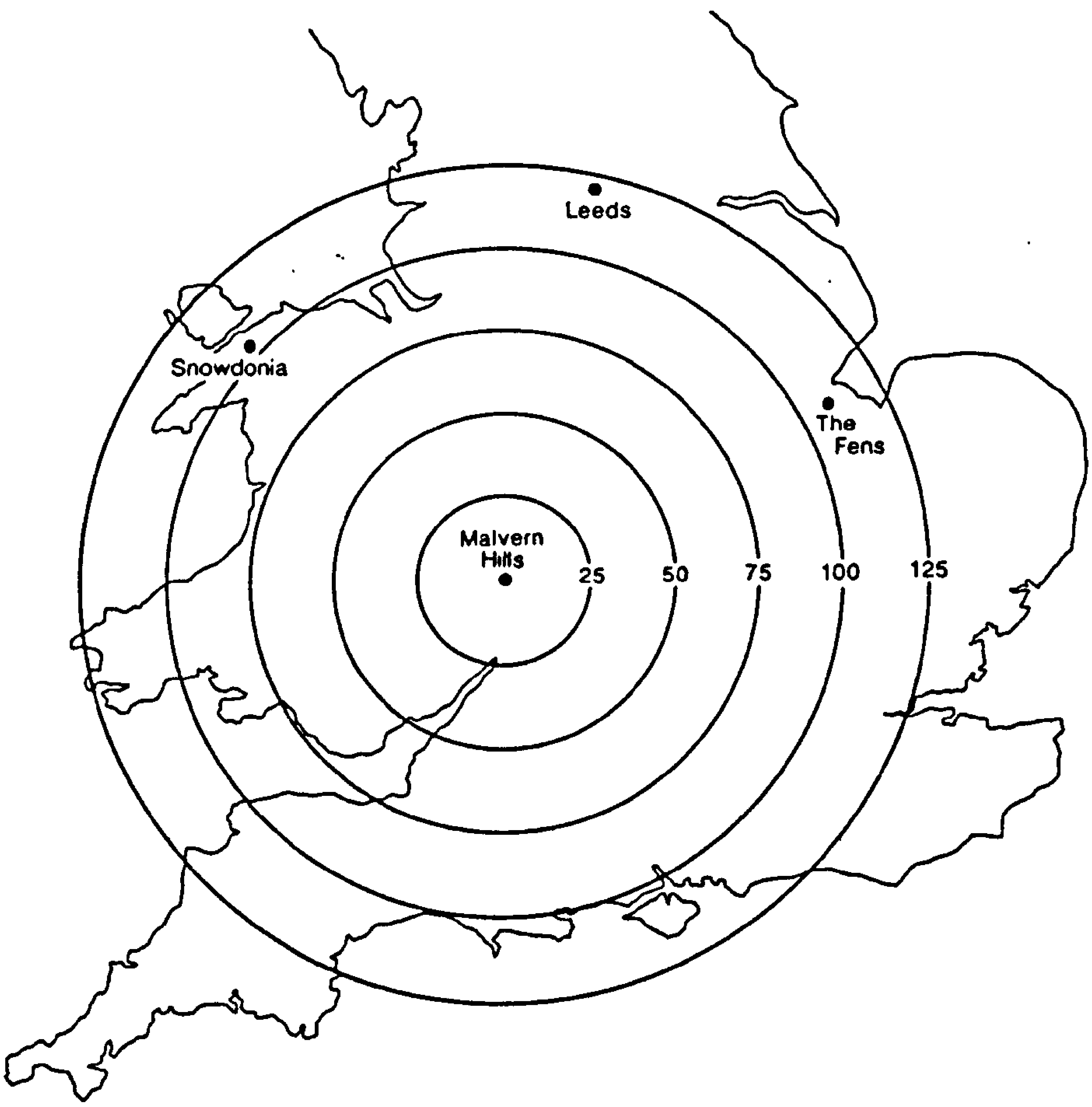
	ZTC		ITC		CS ratio
Forest	Travel Cost Coefficient	CS/visitor (£)	Travel Cost Coefficient	CS/visitor (£)	ZTC/ITC
Brecon	-0.384	2.60	-0.358	1.40	1.86
Buchan	-0.444	2.26	-0.996	0.50	4.52
Cheshire	-0.525	1.91	-1.259	0.40	4.78
Lorne	-0.694	1.44	-0.327	1.53	0.94
New Forest	-0.702	1.43	-0.215	2.32	0.62
Ruthin	-0.396	2.52	-0.386	1.29	1.95

Notes: All coefficients produced via OLS techniques and significant at 5% level
Travel cost defined as full running costs
Consumer surplus estimates at 1988 prices
N = 21 for all forests

Sources: Garrod and Willis (1991), Willis and Garrod (1991b).

There are a number of methodological problems associated with the use of an average value as a dependent variable. The use of a zonal visitor rate means that it is impossible to specify individual-specific explanatory variables. For example membership of an environmental or outdoor pursuits association may well be a highly significant predictor of recreational visits. However in the ZTC such individual characteristics information cannot be used, and a constructed zonal average for such a variable is likely to be highly inefficient (Brown and Nawas, 1973). Similarly, intra-zonal variation is to a considerable degree lost in the ZTC, as inter-zonal average effects dominate in curve-fitting. An extreme case of this may occur where concentric zones are used; outer zones may encompass areas which are geographically very different from each other. For example, suppose that we were to carry out a ZTC study estimating the recreation value of the Malvern Hills (Worcestershire, England) using 25 mile wide distance bands. Here the distance band between 100 and 125 miles from the Malvern Hills encompasses both the Snowdonia Mountains of North Wales and the flat Fenlands of Eastern England (see figure 2.6). It is likely therefore that anyone with a predisposition for hills (as the visitors to Malvern presumably have) would have far more substitute sites if he lived in Snowdonia than if he lived in the Fens. However, ZTC approaches can at best only construct comparisons of the attributes of the studied site with those of all sites perceived by the analyst as substitutes, irrespective of the distance individuals would have to travel to reach such substitutes. Such variables will always be weak compared to the individual-specific substitute variables which can be employed by the ITC.

Figure 2.6: Concentric distance zones around the Malvern Hills



Source: Bateman (1993a)

Figure 2.6 also highlights a problem with the ZTC if straight line distances are equated directly with both travel and time costs. Both Snowdonia and the Fens have relatively poor road links with Malvern whereas Leeds (in the same distance zone) has a direct motorway link. Therefore both time and travel costs from Leeds will be considerably less than those for either of the others, a distinction which may be lost in any zonal average.

A further problem for the ZTC, which again does not afflict the ITC, is that R^2 statistics will always be upwardly biased. This arises as a natural consequence of aggregating individual responses across zones and so reducing the number of curve fitting points to the number of zones. Figure 2.7 illustrates this point. Panel A shows the spread of individual observations recorded in a hypothetical TC survey, each point being represented by a number which in turn is defined by a distance band away from the site. In fitting a demand curve the ITC would employ all these observations as individual points. In panel B these individual observations have been converted into zonal averages for use in a ZTC. The number of observations has thus been reduced to the number of zones (here 6) which will in turn spuriously increase the R^2 of the fitted line.

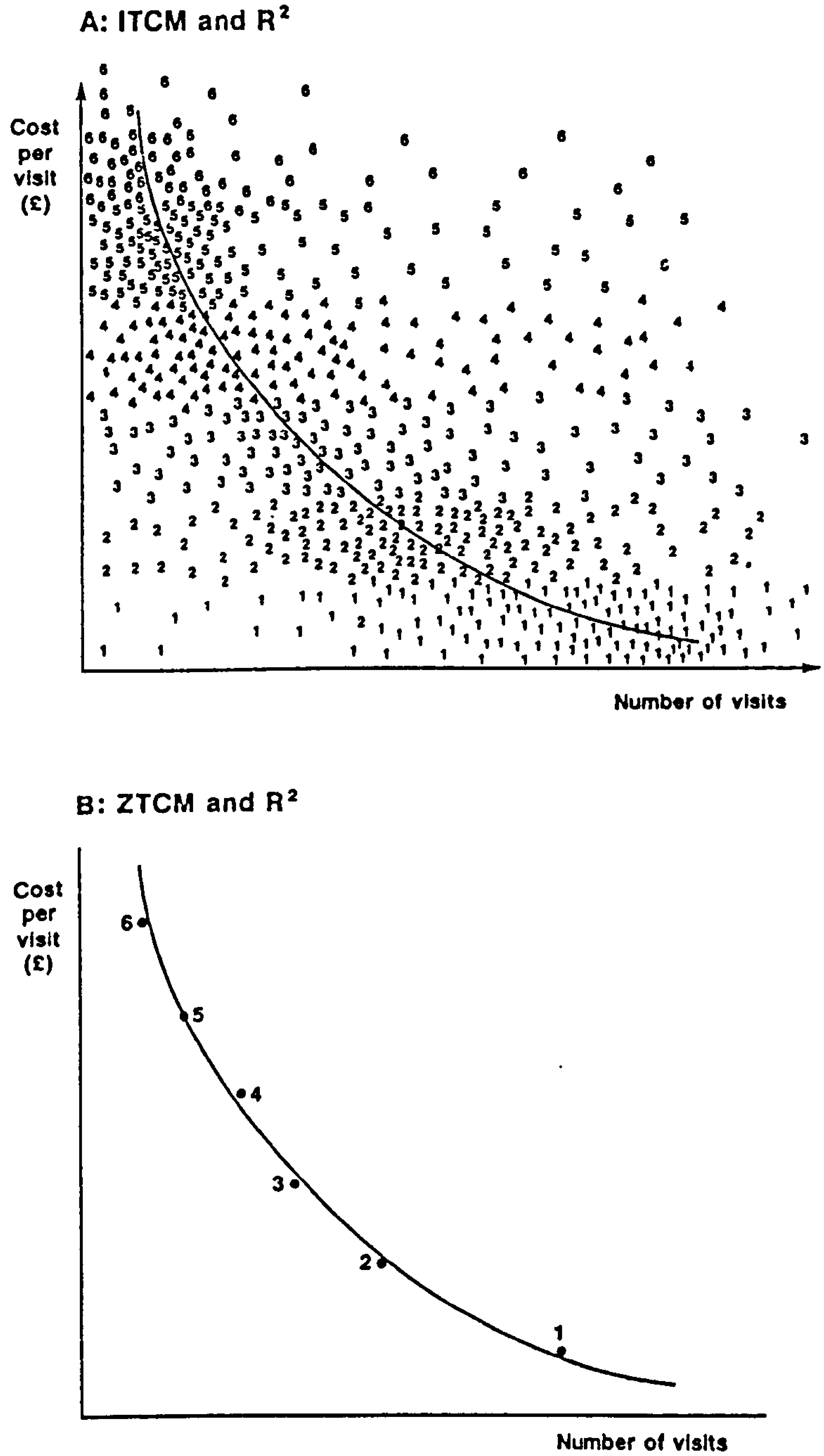
Consequently the very high R^2 values recorded in many ZTC studies should be treated with extreme caution. Their only real validity is as indicators of which model has relatively higher explanatory power within any particular functional form, their absolute value should be disregarded (and even not reported as it may well be misleading). This criticism does not apply to the ITC for which R^2 figures are, in this respect, unbiased.

A final criticism of the ZTC approach arises from the methods by which zones are defined. Zones are conventionally defined as concentric circles. However, this need not necessarily be so[62], for example Böjo (1985) uses county boundaries. The definition of the width and number of zones is typically either arbitrary or influenced by the availability of population data. In effect each possible definition of zones implies a different aggregation of population and in practice almost certainly a different visitor rate. This in turn will imply changes in the estimated demand curve and thereby different consumer surplus estimates. Therefore, in practice, it is almost certain that an analyst could respecify zones so as to either inflate or reduce valuation estimates as required. The extent to which such a change is

[62]Furthermore zones may be cut off at some finite distance although the outer band may be infinite. Englin and Mendelsohn (1991) in their study of rainforest tourism analyse visits from all countries.

possible is uncertain and the subject of our ongoing research[63].

Figure 2.7: R^2 bias in TC studies



Source: Bateman (1993a)

[63]One of the few examinations of the impact of zonal respecification is given by Price et al. (1986) wherein a 10 zone and a 6 zone concentric system are compared, the impact upon consumer surplus being, in this case minimal. In related work, Christensen (1983) examines the impact of changing the zonal population division from visits per 100,000 population to visits per 1000 population. The author is currently examining the problem of zonal respecification.

Brown and Nawas (1973) argue that the ZTC is therefore, at best highly inefficient and therefore prefer the use of the ITC, a sentiment echoed by Gum and Martin (1975) and Bowes and Loomis (1980). Indeed the US literature has over the past two decades slowly moved from use of the ZTC to employing the ITC. However the ITC is not without problems.

Dobbs (1991) points out that most ITC studies to date have incorrectly estimated consumer surplus in that they have ignored the inherently discrete nature of the dependent variable. In such cases the integration of a smooth demand function may lead to significant bias in consumer surplus estimates. However, Dobbs develops a programmable approach to the computation of discrete dependent variable benefits which overcomes this problem.

A more fundamental problem for the ITC occurs where a high proportion of visitors make only one visit per annum or are first time visitors (Freeman, 1979; Bowes and Loomis, 1980). In such cases statistical techniques used in the ITC may not have a sufficient spread of observations to make the technique operational. Ironically, those sites which have the highest proportions of repeat visitors are also those which are most likely to be attracting a high proportion of locally based visits who walk to the site and incur zero monetary travel costs (e.g. Bishop, 1992).

In conclusion the decision to use either zonal or individual TC approaches is likely to have a significant impact upon the results obtained. While there appears no theoretical reason for preferring one approach ahead of the other, this discussion highlights a number of methodological problems associated with the application of both the ZTC and ITC. Our conclusion is that the weight of evidence against use of the ZTC exceeds that of the ITC. This is not an ideal criterion for method selection but it seems to be the basic reason underlying the general preference for ITC applications in the current US and UK literature. We are particularly concerned about the ZTC zonal specification problem and this is avoided by the ITC. Consequently we employ the latter in our travel cost valuation studies. However, we do feel that our use of GIS software provides a route for tackling the most serious problems of the ZTC. In order to demonstrate this potential we use a visitor rate dependent variable in our visitor arrivals prediction models. Here we use GIS routines to define true travel time zones adjusted for road quality. These extend along high quality road corridors rather than using the unrealistic concentric zones employed in conventional ZTC studies. Although we have not extended this approach up to the point of producing ZTC valuations (preferring our ITC) values) this provides an obvious future extension to this work which we shall be pursuing.

2.3.3.10: Non-use values and the relationship with CV estimates

TC measures only the 'use value' of recreation sites. Underestimation of the total value of a site due to the truncation of non-visitors would be made worse if the non-use value of both visitors and non-visitors was significant. TC is not capable of producing any total economic value estimate in that it cannot estimate non-use items such as existence value. This is because the basis of the technique is the level of use-based costs incurred by visitors in visiting a site. If non-use values are thought to be significant then an appropriate methodology (e.g. the contingent valuation method, CV) must be employed to capture these values.

Comparison of CV and TC-derived values may therefore be difficult given the various possible permutation of respondents perception of CV questions. Three potential scenarios can be envisaged[64].

(i) Respondents may perceive CV questions as relating to their total willingness to pay (WTP) for the use value of the good in question[65]. In such a situation CV and TC measures are comparable although even here we may expect some divergence given that the CV produces income-compensated (Hicksian) welfare measures whilst the TC produces uncompensated (Marshallian) consumer surplus measures[66].

(ii) Respondents may perceive CV questions as relating to their total WTP for both the use and non-use value of the good under investigation. In such a situation, once we have made any adjustment with regard to the compensated/uncompensated measures problem of scenario (i), (which will still apply), then we would expect a residual

[64]Further scenarios are considered in Bateman (1993b). In addition to these differences may also occur if post-visit CVM surveys pick up a transformation value effect.

[65]Several permutations of scenario (i) and (ii) are possible given the four feasible variants of CVM question: WTP or willingness to accept (WTA) compensation for a welfare gain or welfare loss. See earlier discussion and Bateman and Turner (1992) where additional complications surrounding asymmetry of gains and losses are also reviewed.

[66]As noted previously, whereas standard economic theory would lead us to expect that the divergence between compensated and uncompensated welfare measures will be small, recent theoretical advances have shown that this may not be the case for public goods such as those provided by the environment, i.e. the divergence between CVM and TCM measures under scenario (i) may not be insignificant (see also Bateman and Turner, 1993).

difference between CV and TC measures such that CV > TC measure[67].

(iii) If the CV payment vehicle asks respondents for their WTP per visit, frequent visitors may well offer lower sums than occasional visitors in an effort to reduce the formers total annual payments. Such strategies may arise from a variety of motivations. For example occasional visitors may derive greater marginal utility from a visit than do regular visitors. Alternatively, as frequent visitors may face a higher burden of overall costs they may have a greater incentive to indulge in free-riding behaviour. Whatever the motivation, if such a result pertains we will find an inverse relationship between CV per visit WTP and the TC measure, which has little to do with their Hicksian and Marshallian roots.

These are interesting relationships and consequently comparison of CV and TC welfare measures was made a focus of our applied research.

2.3.3.11: Variants of the TC

Apart from those already discussed, a number of variants on the TC have been developed (see review in Bateman, 1993a). Most relevant to this study is the Hedonic TC (HTC) approach developed by Brown and Menddsohn (1984) in which the property prices of the hedonic price method are replaced with travel costs. The HTC uses travel costs to estimate values for separate site attributes rather than whole site values. A two stage estimation process is employed. In stage one the independent variables (including characteristic levels for each of the k site attributes) are regressed, in separate estimations, against total travel costs[68]. The implicit price[69] of each attribute can then be calculated. Stage two involves the estimation of demand curves for each attribute by regressing implicit price on the observed level of the attribute and other explanatory variables[70]. Summing over all observations gives an aggregate demand function for each attribute from which consumer surplus estimates may be obtained. While the HTC method has had considerable recent

[67]Note that the adjustment arising from scenario (i), which still applies, may feasibly outweigh that arising from scenario (ii).

[68]Brown and Mendelsohn (1984) only consider travel time, i.e. they assume that on-site time is a constant, a separate regression (on site time cost) equation would be required if this were not the case.

[69]The implicit price tells us the value of a marginal improvement in attribute i.

[70]These include income, other socio-economic variables and the predicted number of trips from each zone, the latter being derived from a standard TC tgf.

application[71] its extreme data requirements have cast doubt upon its practical decisionmaking applicability. In particular it is questionable as to whether the relevant site characteristics may be identified a priori and accurately measured.

In chapter 3 we consider an application of the HTC method (Hanley & Ruffell, 1992). However, as this review reveals the extreme problems of the HTC approach we do not pursue it in our own applied work.

2.3.4: CONCLUSIONS: THE TRAVEL COST METHOD

The TC method is a potentially useful evaluation tool producing uncompensated consumer surplus estimates of use value. It is best applied to the evaluation of well defined recreation resources such as those provided at forest sites. This survey has highlighted several potential problems which may arise during the practical application of the TC method. These include;

i. The decision whether to use zonal and individual approaches and variation in results between these methods.

ii. Calculation of the cost elements and in particular determination of the opportunity cost of on-site and travel time.

iii. Multicollinearity between explanatory variables especially site environmental characteristic levels.

iv. Problems of heteroskedasticity.

v. Treatment of substitute sites.

vi. Accounting for potential congestion effects.

vii. Choice of the appropriate functional form and its impact upon consumer surplus estimates.

viii. Truncation bias and the choice of appropriate estimation technique.

We have outlined our approach to each of these problems. In subsequent chapters we discuss the practical implementation and results of our TC studies and assess our effectiveness in addressing these methodological issues.

[71]Further examples of the HTC approach include Loomis et al. (1986); Bell and Leeworthy (1990); Bowes and Krutilla (1989); Englin and Mendelsohn (1991); and Hanley and Ruffell (1992). The latter three studies all describe applications to forestry.

2.4: VALUATION METHODS: CONCLUSIONS

This chapter has provided an overview of methods for the monetary assessment of environmental goods and a more detailed theoretical and methodological review of the two methods chosen for application in subsequent empirical work: the contingent valuation, and travel cost methods. We have also indicated how we have addressed the various methodological problems raised by the implementation of these methods. In chapter 3 we discuss and present results from our applied evaluation work using these methods.

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Chapter 3: Recreation:
Previous Valuation Studies

3.1: LITERATURE REVIEW

In conducting an extended CBA of agro-forestry conversion, a principle aim of this research was to incorporate monetary evaluations of the recreational value of woodland. This we aimed to achieve both through analysis of existing estimates produced by others and through our own original research. This chapter presents results from the former review of existing literature and our investigation of the potential for using these results to provide benefit transfer measures of recreation value for use in our CBA model.

In the UK there have been more applications of the CV and TC to the evaluation of woodland recreation than to any other open-access recreational good[1]. Indeed this factor heavily influenced our decision to conduct an extended CBA of land conversion to woodland as opposed to other natural resources such as wetlands, etc. Our detailed literature review is presented in appendix 1 to this study. This presents commentary and critique of over 40 papers containing over 100 monetary evaluation estimates[2]. Due to space restrictions, in this chapter we provide only the briefest summary of this review concentrating upon bringing together valuation estimates to allow a consideration of the possibilities of benefit transfer analysis.

Section 3.2 (and subsections) presents valuation estimates from reviewed papers in a condensed tabular form. These estimates are subdivided according to both the evaluation method employed and the specific type of values elicited, e.g. per annum; per visit; etc. Brief comments regarding the feasibility of conducting benefit transfer analyses on each category of results are also given. Section 3.3 (and subsections) presents our attempts to conduct benefit transfer analyses upon those categories of evaluation highlighted for such work in the

[1]We have excluded non-UK studies as we believe that the uncertainties surrounding relevant cultural and socio-economic differences between countries such as the USA (where the majority of evaluation work has been conducted) and the UK make such extrapolations of highly dubious value. Loomis (1996) provides a review of non-UK evaluations of forestry preservation benefits conducted using the CV method.

[2]In addition a considerable number of related papers are reviewed. The 100-plus evaluation estimates referred to above does not include a plethora of sensitivity analysis estimates within these papers where the impact of altering assumptions is assessed.

preceding section. Finally section 3.4 summarises and concludes this chapter.

3.2: SUMMARY RESULTS TABLES

In this section we summarise, in tabular form, results from the papers reviewed in appendix 1. This summary is divided into four subsections as follows:

i. Annual national values for the entire Forestry Commission estate obtained from TC studies;

ii. Capitalised per household sums obtained by asking for once-and-for-all payments in CV studies;

iii. Annual per person values obtained from CV studies;

iv. Per person per visit amounts obtained from both TC and CV studies.

To allow comparison between studies all results are given both as reported and indexed to 1990 prices (the base year for our subsequent analysis of agricultural values) using indices given in CSO (1981, 1992).

Where appropriate we have included summary results from our own studies (detailed in chapter 4) to permit comparison with those from other UK authors.

3.2.1: ANNUAL NATIONAL VALUES

3.2.1.1: H.M. Treasury TC study

One of the earliest attempts to evaluate, in monetary terms, the open-access recreation value of woodland is given in the Treasury's 1972 interdepartmental CBA of the Forestry Commission (H.M. Treasury, 1972). This built upon an earlier unpublished study of visitor arrivals and visit patterns conducted by the Department of the Environment. The CBA therefore adopted a hybrid TC approach to produce both national and conservancy estimates of recreation value. Details of these estimates are given in table 3.1. The study is important both because it marked the official acceptance of monetary evaluations of forestry externalities[3] and because the estimates produced dominated official thinking and funding of

[3]Although it is interesting to note that the Treasury has seemed reluctant to accept such valuations when they are not conducted "in-house" (Ken Willis, *pers. comm.* 1994).

the Forestry Commission until at least the late 1980's (NAO, 1986; PAC, 1987). However, while the estimates produced are of historical and policy interest, our review (appendix 1) shows that they were obtained using rather dubious assumptions and methodological short-cuts and are therefore not considered suitable for benefit transfer purposes.

Table 3.1: H.M.Treasury (1972) TC recreation values for the Forestry Commission (FC) estate and by conservancy.

Study	Forest	Unit	Value (£)	Base Year	1990 Value (£)
Treasury (1972)	All FC forests	UK (FC) aggregate	1,113,200	1970	7,575,928
ibid	England NW	Conservancy aggregate	99,400	1970	676,471
ibid	England NE	Conservancy aggregate	100,800	1970	685,999
ibid	England E	Conservancy aggregate	161,300	1970	1,097,734
ibid	England SE	Conservancy aggregate	125,300	1970	852,734
ibid	England SW	Conservancy aggregate	154,100	1970	1,048,734
ibid	New Forest	Forest aggregate	129,600	1970	881,998
ibid	Dean	Forest aggregate	27,400	1970	186,472
ibid	Scotland N	Conservancy aggregate	51,100	1970	347,763
ibid	Scotland E	Conservancy aggregate	23,000	1970	156,527
ibid	Scotland S	Conservancy aggregate	15,800	1970	107,528
ibid	Scotland W	Conservancy aggregate	89,300	1970	607,735
ibid	Wales N	Conservancy aggregate	61,200	1970	416,499
ibid	Wales S	Conservancy aggregate	74,900	1970	509,735

3.2.1.2: Other ZTC and ITC studies

The National Audit Office economic analysis of Forestry Commission operations highlighted an apparent inability of benefits to match current grant-in-aid but recognised that the estimates of recreational value used in this appraisal (which were based upon H.M.Treasury, 1972) might be a substantial understatement of true values. Accordingly it was as part of a wider attempt to justify its continued existence that the forestry Commission supported a number of evaluation studies, most notably the per visit and national value studies of Willis et al. Table 3.2 brings together estimates of the national recreational value of the entire Forestry Commission estate. All figures are estimated via the ZTC except for Willis and Garrod (1991) who employ the ITC. The H.M. Treasury (1972) result is repeated for comparison. Indexing to 1990 prices is undertaken using indices given in CSO (1981, 1992) with the base year being chosen to allow comparison with the agricultural values discussed in subsequent chapters.

Table 3.2: National recreation values for the entire Forestry Commission estate, from various studies from ZTC and ITC studies (£ pa.)

Study	Forest	Method	Value (£)	Base Year	1990 Value (£)
Treasury (1972)	All FC forests	ZTC	1,113,200	1970	7,575,928
Grayson et al (1975)	All FC forests	ZTC	1,050,000	1971	6,530,924
NAO (1986)	All FC forests	ZTC	10,000,000	1986	12,891,021
Willis and Garrod (1991)	All FC forests	ITC	8,665,000	1988	10,221,296
Benson and Willis (1992)	All FC forests	ZTC	52,999,000	1988	62,517,997
Benson and Willis (1992)[1]	All FC forests	ZTC	39,615,414[1]	1988	46,730,624[1]

Note: [1] Re-estimate based upon our recalculated result ([3*], see appendix 1 and section 3.3.2 in this chapter) using an all UK mean value of £1.48 per forest visit applied to the findings of Benson and Willis (1992).

Table 3.2 highlights a considerable controversy regarding the national recreational value of the Forestry Commission estate. Early studies (up to and including the NAO report) can be discounted because of the rather crude assumptions used in their preparation. However there is a clear disparity between estimates produced by Benson and Willis (1992) using the ZTC and those of Willis and Garrod (1991) using the ITC. This is particularly disturbing given that both are using the same dataset, i.e. we cannot put this difference down to survey design discrepancies. In the final row of table 3.2 we report our reworking of the Benson and Willis (1992) results based upon what we see as more defensible and data supported assumptions regarding definitions of the cost variable (see appendix 1 for details). This results in a considerable reduction in the estimate of national recreational value. However, the discrepancy with respect to the ITC results remains. In our review of the Willis et al. ZTC and ITC paper's (see appendix 1) we show that, while the specification of explanatory variables is superior in the ITC study, this latter paper uses a theoretical indefensible and statistically weak linear functional form. As we show in chapter 4, changes in the functional form of the trip generation function (tgf) estimated in TC studies can have very major impacts upon resultant estimates of consumer surplus. Therefore, while we have argued in chapter 2 for a general superiority of ITC over ZTC approaches, in this case we have considerable doubts regarding the estimates produced by this particular ITC study. This of course does not mean that our criticisms of the ZTC do not stand and as a result of these problems we do not feel that the estimates produced in table 3.2 can be disaggregated for benefit transfer purposes.

As a postscript to this work, in a recent appraisal H.M.Treasury rejected all the above estimates and used a figure of £1 per visit in calculating the recreational value of the Forestry Commission estate (Ken Willis, *pers. comm.*, 1994). It is unclear how this figure was arrived at and it is likely to simply be a "guesstimate". However, with visits estimated at over 26 million per annum (Benson and Willis, 1992), this would provide an evaluation which sits quite nicely between those of the ITC and ZTC analysis discussed above.

3.2.2: PER HOUSEHOLD CAPITALISED VALUES

The evaluation estimates detailed in table 3.3 were produced using CV household (rather than on-site) surveys employing a per household, capital sum (once-and-for-all) WTP measure. We have classified these studies according to whether they interviewed households which were proximal to the resource in question or not (the distance definition of proximal being, admittedly, subjective), the implication being that proximal studies interview more users and potential users than do non-proximal surveys.

Table 3.3: Capitalised (once-and-for-all) household recreation values from CV studies (£/household pa.)

Study	Forest	Distance to forest	Value (£)	Base Year	1990 Value (£)
Hanley and Munro (1991)	Birkham Wood	proximal	12.89	1990	12.89
Hanley and Ecotec (1991)	Central Scotland Woodlands	proximal	9.34	1990	9.34
Hanley and Craig (1991)	Flow Country	non- proximal	3.27[1]	1990	3.27[1]

Notes: Proximal households are those which live nearby to the forest, whether existing (e.g. Birkham Wood) or planned (e.g. Central Scotland Woodlands), as opposed to non-proximal households who do not.

[1] We have recalculated these figures by including those who refused to pay as zero bids (see details in appendix 1). This considerably reduces the reported mean but is, we argue, consistent with a conservative design (as per Arrow et al., 1993) and is therefore theoretically more defensible.

Given the socioeconomic differences between households surrounding Birkham Wood (near Knaresborough, Yorkshire) and the Central Scottish Woodlands Project and the fact that the latter is a projected new wood whilst the former is both in existence and encompasses certain ancient woodland, the ordering of these two results is as expected. Similarly the expected difference in WTP for proximal and non-proximal woodlands is reflected in comparison of results for both the above with those for the Flow Country study[4].

Comparing these results with the annual payments expressed by users in on-site surveys (see section 3.2.3) we can see that the above are lower than the likely capitalised equivalents of annual sums stated by such users[5]. This is again as expected, indicating that the WTP of a group composed entirely of users exceeds that of even a proximal sample of

[4]This distance decay effect accords with that found by Bateman et al. (1992) in their non-user survey of WTP to preserve the Norfolk Broads.

[5]However, some support for this apparent discrepancy is given in the high implicit recreational discount rate reported by Bateman et al. (1992) in their comparison of annual and capitalised CV WTP question formats.

households which will contain both users and non-users. However, the work of Bateman et al., (1992) indicates that respondents find once-and-for-all formats difficult to comprehend and often fail to answer such questions (a finding echoed in the studies listed in table 3.3). We must therefore be cautious regarding the accuracy of estimates obtained from such studies and do not pursue their use for benefit transfer purposes.

3.2.3: PER PERSON ANNUAL VALUES

Table 3.4 brings together results from CV surveys employing annual, per person, measures. All results were gathered using on-site surveys and therefore represent the values expressed by users. Respondents were asked to state either their use value or their use + option value as indicated. Details regarding the payment vehicle employed are also given. We have included summary results from two of our studies using per person per annum instruments. Of these, only the Thetford 2 result is strictly comparable as the Thetford 1 study informed respondents of the existing tax payments for forestry, a factor which subsequent analysis found to have had a significant anchoring effect upon responses (details of both studies are given in chapter 4). The studies by Maxwell (1992) and Tranter et al., (1994), reviewed earlier in appendix 1, are omitted from the following table as neither specifies whether the per annum results reported are per person or per household.

The ordering of results is as expected. The Whiteman and Sinclair (1994) studies examine use values while Bishop (1992) examines use + option value and as expected, reports the higher values. This difference may well be exacerbated by the fact that whereas Bishop addresses values for existing woods, Whiteman and Sinclair examine WTP for proposed forests. We would expect the lack of experience and uncertainty regarding the likelihood of provision to lead to lower WTP for proposed as opposed to existing woodlands. Ordering within these sets of studies also appears logical with higher income areas recording higher willingness to pay throughout.

Comparison with our own studies is interesting and gives some cross-study validation. As the Thetford 2 study examines use value alone, the relationship with Bishop's use + option value results is as expected. Similarly, although both the Thetford 2 and Whiteman and Sinclair studies examine use value alone, as our study is of an existing forest while their's is of a proposed woodland, the observed disparity of values is again in accordance with expectations.

Table 3.4: Forest users annual recreation values from CV studies (£/person pa.)

Study	Forest	Value type / payt. vehc.	Value (£)	Base Year	1990 Value (£)
Whiteman and Sinclair (1994)	Mercia	use TAX	7.70	1992	7.12
ibid	Thames Chase	use TAX	9.79	1992	9.06
ibid	Gt. Northern Forest	use TAX	8.66	1992	8.01
Bishop (1992)	Derwent Walk	use+option SUB	18.53	1989	20.28
ibid	Whippen-dell Wood	use+option SUB	27.03	1989	29.59
Bateman[1]	Thetford 2 (t1NB)[2]	use TAX	12.32	1993	11.22
ibid	Thetford 1	use TAX	5.14[3]	1990	5.14[1]

Notes: 1. Full details of all our studies are given in chapter 4.
2. The Thetford 2 study conducts a number of split sample experiments investigating mental account and ordering effects. The result reported in table 3.4 refers to the t1NB subgroup which is the only one comparable with the other studies included in this table. Full details are given in chapter 4.
3. In the relevant subgroup of the Thetford 1 study, respondents were informed of current average annual per household tax payments for Forestry Commission woodlands (£2.70 pa). This was found to have biased WTP responses downwards towards this amount. Full details are given in chapter 4.

Terms in capitals in the third column indicate the payment vehicle used. These are as follows:
SUB = subscription to private ownership shares allowing free entry to the wood;
TAX = payment via direct income tax.

Our Thetford 1 annual use value study differs significantly from all the others summarised here in that respondents were informed of their present level of tax expenditure in respect of Forestry Commission woodlands (£2.70 pa in the 1990 study year). This appears to have significantly, downwardly biased mean WTP relative to all other studies and we consequently have serious doubts regarding the validity of this result.

All the above studies employed a taxation payment vehicle with the exception of Bishop (1992) who uses subscriptions to private ownership shares allowing free entry to the wood. Evidence exists to support the use of tax rather than private subscription vehicles. Bateman and Turner (1993) argue that, where a tax vehicle is liable to be the actual route for funding, selection of an alternative vehicle may exacerbate hypothetical bias in responses. Furthermore, in empirical comparisons of payment vehicle effects, Bateman et al., (1993) report that non-tax vehicles (particularly those proposing annual donations similar to those used by Bishop) suffer disproportionately from high refusal to pay rates. It is regrettable that Bishop (1992) does not report such rates[6].

3.2.3: PER PERSON PER VISIT VALUES

The per person (and per party) per visit measure was found to be highly useful in our subsequent CBA. In part this was due to the wider availability of studies using such a measure. The studies reviewed in appendix 1 contain relevant results estimated via ITC, ZTC and CV studies.

3.2.3.1: ITC studies

The ITC studies reviewed give per person per visit estimates of the Marshallian consumer surplus value of woodland recreation. The results reported in table 3.5 all employ a (best fitting) full travel cost assumption. Ordinary least squares (OLS) and maximum likelihood (ML) estimation techniques are used as indicated.

As table 3.5 shows there have been very few per person per visit ITC studies of woodland recreation conducted in the UK to date. The bulk of these are contained within the Willis and Garrod (1991) paper and, as detailed in section 3.2.1.2 above, we have certain reservations concerning the functional form of the tgf used in these studies (detailed criticism is left to appendix 1). This means that we are left with just the point estimates given in our own ITC studies as detailed in chapter 4. While we can use these as stand alone estimates this does rule out the possibility of cross-study ITC 'meta-analyses', such as that conducted by Smith and Kaoru (1990), for the foreseeable future.

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[6]A further problem arising from this non-reporting is that we are not certain as to the treatment of refusals in the calculation of means. We argue that all non-protest refusals should be included as zeros in such calculations and adopt such an assumption in all our CV studies.

Table 3.5: Forest users per person per visit recreation values from ITC studies (£/person/visit)

Study	Forest	Regression method	Value (£)	Base year	1990 value (£)
Willis and Garrod (1991)	Brecon	OLS	1.40	1988	1.65
ibid	Buchan	OLS	0.50	1988	0.59
ibid	Cheshire	OLS	0.40	1988	0.47
ibid	Lorne	OLS	1.53	1988	1.80
ibid	New Forest	OLS	2.32	1988	2.74
ibid	Ruthin	OLS	1.29	1988	1.52
ibid	Brecon	ML	0.66	1988	0.78
ibid	Buchan	ML	0.20	1988	0.24
ibid	Cheshire	ML	0.06	1988	0.07
ibid	Lorne	ML	0.96	1988	1.13
ibid	New Forest	ML	0.12	1988	0.14
ibid	Ruthin	ML	0.88	1988	1.03
Bateman[1]	Thetford 2[2]	ML	1.32	1993	1.20
ibid	Thetford 1[3,4]	OLS	1.07	1990	1.07
ibid	Thetford 1[3,5]	OLS	1.19	1990	1.40
ibid	Thetford 1[3,6]	OLS	1.34	1990	1.58

Notes: 1. Full details of all our studies are given in chapter 4.
2. Thetford 2 result is for best fitting (variable value of time) model.
3. All Thetford 1 estimates use the best fitting double log model
4. Makes no valuation distinction between an adult and a child (under 16) visitor
5. Weights one child as 0.5 adult visitors
6. Omits child visitors

3.2.3.1: ZTC studies

Table 3.6 gives results from three separate ZTC studies but is dominated by the multi-site analysis of Benson and Willis (1992). The figures reported for this particular study are from their 'Standard Model' [SM] where travel expenditure is calculated upon full costs of 33p per mile and travel time is valued at 43% of wage rate (see discussion of tgf cost definitions in chapter 2 and review in appendix 1).

Table 3.6: Forest users per person per visit recreation values from ZTC studies (£/person/visit)

Study	Forest	Value (£)	Base Year	1990 Value (£)
Benson and Willis (1992)	New Forest	1.43	1988	1.69
ibid	Cheshire	1.91	1988	2.26
ibid	Loch Awe	3.31	1988	3.91
ibid	Brecon	2.60	1988	3.07
ibid	Buchan	2.26	1988	2.67
ibid	Durham	1.64	1988	1.94
ibid	N York Moors	1.93	1988	2.28
ibid	Aberfoyle	2.72	1988	3.21
ibid	South Lakes	1.34	1988	1.58
ibid	Newton Stewart	1.61	1988	1.90
ibid	Lorne	1.44	1988	1.70
ibid	Castle Douglas	2.41	1988	2.85
ibid	Ruthin	2.52	1988	2.98
ibid	Forest of Dean	2.34	1988	2.76
ibid	Thetford	2.66	1988	3.14
ibid	Mean (all forests)	1.98	1988	2.34
Hanley (1989)	Aberfoyle	1.70	1987	2.14
Everett (1979)	Dalby	0.41	1976	1.30

In addition to the studies given in table 3.6, Christensen (1985) produces a ZTC estimate of consumer surplus per visitor group of £0.37 in 1980 prices. Indexing to 1990 gives a value of £0.70. Given that this is a per group rather than per person estimate, this is significantly lower than any of the above studies. Christensen gives a warning regarding the poor quality of data used in what was primarily a methodological investigation, and consequently this result has been omitted from our table and subsequent analyses.

An initial inspection suggests that the studies collected in table 3.6 might be sufficient to form the basis of some sort of benefit transfer analysis. This is given further consideration subsequently.

3.2.3.1: CV studies

All the results summarised in table 3.7 were derived from CV WTP studies of per person recreation value employing an entrance fee payment vehicle. A variety of elicitation methods were used as were both direct 'use' and 'use + option' value formats as indicated.

Table 3.7: Forest users per person per visit recreation values from CV studies (£/person/visit)

Study	Forest	Value type/ Elicit. method	Value (£)	Base Year	1990 Value (£)
Whiteman and Sinclair (1994)	Mercia	use OE	1.00	1992	0.93
ibid	Thames Chase	use OE	0.71	1992	0.66
ibid	Gt. Northern Forest	use OE	0.81	1992	0.75
Hanley and Ruffell (1992)	Mean of 57 forests	use OE	0.93	1991	0.88
ibid	Mean of 57 forests	use OE	0.84[1]	1991	0.79[1]
Hanley and Ruffell (1991)	Aberfoyle	use OE	0.90	1991	0.85
ibid	Aberfoyle	use IB	1.21	1991	1.14
ibid	Aberfoyle	use PC	1.39	1991	1.31
ibid	Aberfoyle	use DC	1.49	1991	1.41

Study	Forest	Value type/ Elicit. method	Value (£)	Base Year	1990 Value (£)
Bishop (1992)	Derwent Walk	use OE	0.42	1989	0.46
ibid	Derwent Walk	use+option OE	0.97	1989	1.06
ibid	Whippen-dell Wood	use OE	0.54	1989	0.59
ibid	Whippen-dell Wood	use+option OE	1.34	1989	1.46
Willis and Benson (1989)	New Forest	use OE	0.43	1988	0.47
ibid	Cheshire	use OE	0.47	1988	0.51
ibid	Loch Awe	use OE	0.50	1988	0.55
ibid	Brecon	use OE	0.46	1988	0.50
ibid	Buchan	use OE	0.57	1988	0.62
ibid	Newton Stewart	use OE	0.73	1988	0.80
ibid	Lorne	use OE	0.72	1988	0.79
ibid	Ruthin	use OE	0.44	1988	0.48
ibid	Mean (all forests)	use OE	0.53	1988	0.58
ibid	New Forest	use+option OE	0.88	1988	0.96
ibid	Cheshire	use+option OE	0.72	1988	0.79
ibid	Loch Awe	use+option OE	0.76	1988	0.83
ibid	Brecon	use+option OE	0.66	1988	0.72

Study	Forest	Value type/ Elicit. method	Value (£)	Base Year	1990 Value (£)
ibid	Buchan	use+option OE	0.79	1988	0.86
ibid	Newton Stewart	use+option OE	1.18	1988	1.29
ibid	Lorne	use+option OE	1.02	1988	1.12
ibid	Ruthin	use+option OE	0.63	1988	0.69
ibid	Mean (all forests)	use+option OE	0.82	1988	0.90
Hanley (1989)	Aberfoyle	use OE	1.24	1987	1.53
ibid	Aberfoyle	use PC	1.25	1987	1.55
Willis et al (1988)	Castle Douglas	use OE	0.37	1987	0.46
ibid	South Lakes	use OE	0.39	1987	0.48
ibid	North York Moors	use OE	0.53	1987	0.66
ibid	Durham	use OE	0.31	1987	0.38
ibid	Thetford	use OE	0.23	1987	0.28
ibid	Dean	use OE	0.28	1987	0.35
ibid	Castle Douglas	use+option OE	0.80	1987	0.99
ibid	South Lakes	use+option OE	0.86	1987	1.06
ibid	North York Moors	use+option OE	1.03	1987	1.27
ibid	Durham	use+option OE	0.56	1987	0.69

Study	Forest	Value type/ Elicit. method	Value (£)	Base Year	1990 Value (£)
ibid	Thetford	use+option OE	0.41	1987	0.51
ibid	Dean	use+option OE	0.63	1987	0.78
Bateman[2]	Thetford 2 (f2NB)[3]	use OE	0.52	1993	0.47
ibid	Thetford 1	use PCL	1.21	1990	1.21
ibid	Thetford 1	use PCH	1.55	1990	1.55

Notes:

Elicitation methods are as follows:
OE = open ended
IB = iterative bidding
PC = payment card
PCL = payment card (low range)
PCH = payment card (high range)
DC = dichotomous choice

Valuation categories investigated are as follows:
use = use value
option = option value (the extra WTP to ensure conservation of the site for future use).

Notes: 1. Derived from a per household value of £2.00 (1990 prices) converted to a per person per visit value using an average UK household size of 2.53 persons given in CSO (1990).
2. Full details of all our studies are given in chapter 4.
3. The Thetford 2 study conducts a number of split sample experiments investigating mental account and ordering effects. The result reported in table 3.7 refers to the f2NB subgroup which is the only one comparable with the other studies included in this table. Full details are given in chapter 4.

With the exception of our Thetford 1 experiment, all the studies listed in table 3.7 vary according to three major factors as follows:

i. Questionnaire design (for which we can use authorship as a proxy);

ii. Whether the study addressed 'use' or 'use + option' value;

iii. Elicitation method.

In the following section we consider the potential of conducting benefit transfer analyses upon our reviewed studies.

3.3: BENEFIT TRANSFER ANALYSIS OF REVIEWED VALUATION STUDIES

To what extent can the results obtained in those studies reviewed (and indeed our own studies) be applied to other woodland areas? This issue of benefit transfer has in recent years developed into a major area of research[7]. The advantages of a rigorous approach to benefits transfer are clear. The costs, both financial and temporal, of conducting individual evaluations at each site involved in a planning policy are prohibitive. Consequently the US Environmental Protection Agency and, more recently, several UK government departments and agencies have shown considerable interest in this avenue of research[8]. However, as the numerous eminent US commentators acknowledge, the problems raised in formulating and conducting a successful benefits transfer are numerous and extreme (Desvousges et al., 1992; Smith, 1992; McConnell, 1992; Atkinson et al., 1992).

Despite the interest in benefit transfer work, few major applied studies exist. Of these the most notable are those of Smith and Kaoru (1990) and Walsh et al., (1992). Both claim to have adopted a meta-analysis approach[9]. This is a statistical technique designed specifically for synthesising results across studies. However, if we examine the rigorous requirements of meta-analysis (Wolf, 1986) we can see that, to date, the raw material provided by individual benefit evaluations has generally been unsuitable for such a technique. Meta-analysis was originally designed for cross-assessment of medical trials conducted to precisely replicated formats. The further that raw data deviates from such specifications the more suspect are the inferences of cross-analysis. Glass et al., (1981) highlight a variety of problems with meta-analyses, the most important ones being that base studies often employ varying definitions of variables and that poorly designed studies are not excluded from consideration[10].

The rigorous demands of full meta-analysis have yet to be met in any benefits transfer study. This is primarily because of the lack of a sufficiently large, consistently derived, and

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[7]Loomis (1992) actually traces research into benefits transfer back to 1962. However, it is only in the late 1980's that this became a major focus of research. See review by Garrod and Willis (1994).

[8]The author has on separate occasions been approached by the Department of the Environment, Department of Transport and National Rivers Authority with regard to the potential for conducting benefits transfer work. For reasons explained in the text, such offers have not been pursued.

[9]For a lucid introduction to meta-analysis see Wolf (1986).

[10]Other major problems are that insignificant results may not be published leading to a bias towards significant results, and that multiple results from the same study may be treated as individual, independent observations.

comparable dataset of individual evaluation studies. Our review of existing UK studies also revealed that many of these are often insufficiently reported in terms of questionnaire design and data statistics to satisfy the demands of a true meta-analysis[11]. The US approach to this problem (Smith and Kaoru, 1990; Walsh et al., 1992) has been to perform a simplified partial analysis focusing upon the mean benefits measure reported in each source study and relating this, to a series of simple (usually binary) explanatory variables detailing: the evaluation method employed; the type of resource studied; the measurement unit; the elicitation method used; etc. Our 'benefit transfer' study of reviewed articles derives directly from such an approach. Given that we are only considering woodland recreation studies, we obviously do not need to define variables detailing the type of good evaluated[12]. Remaining explanatory factors were intended to be treated (as above) via definition of relevant binary variables. However, for reasons discussed below, such an approach only proved feasible for those studies adopting the CV. Reviewed studies using the ITC and ZTC had to be assessed upon a more ad-hoc basis.

3.3.1: ITC Studies

As indicated in section 3.2.3.1 there have been insufficient UK ITC to perform a benefit transfer analysis. Furthermore, as discussed in our detailed review (appendix 1), we have considerable reservations regarding the validity of point estimates derived from reviewed ITC studies to date. For completeness table 3.8 reports descriptive statistics for all studies excluding our own.

Table 3.8 indicates that, on average, mean consumer surplus in reviewed ITC studies was higher for those using OLS as opposed to ML estimation techniques. Table 3.9 provides an analysis of variance for these two groups of studies which confirms this general trend but shows that this difference is not statistically significant. We have reproduced mean results from our own OLS and ML estimated ITC studies at the end of this table. While the former lies within the 95% CI of reviewed studies the latter does not. Given our considerable

[11]As part of our review we attempted to gather full descriptive statistics on all results. However, the standard of reporting was too variable and incomplete to allow us to complete this task. The issue of consistent and full reporting must be tackled if benefit transfer work is ever to be successfully undertaken in the UK.

[12]In a separate study we present a simple analysis of valuations across differing recreational experiences noting that results were logically related to both the substitutability of the environmental resource concerned and the magnitude of the change in provision considered (Bateman, Willis and Garrod, 1994).

reservations concerning results from reviewed UK ITC studies (see appendix 1), we do not feel that extrapolation of such findings to other forests is justified and are confident in preferring our own ITC results here.

Table 3.8: Descriptive statistics for reviewed ITC studies (mean CS in £/person/visit)

	OLS Studies	ML Studies	All Studies
n	6	6	12
mean	1.462	0.565	1.013
median	1.585	0.510	0.905
tr. mean	1.462	0.565	0.935
st. dev	0.840	0.472	0.801
s.e. mean	0.343	0.193	0.231
minimum	0.470	0.070	0.070
maximum	2.740	1.130	2.740
Q1	0.560	0.123	0.297
Q3	2.035	1.055	1.617

Table 3.9: Analysis of variance: reviewed ITC studies (mean CS £/person/visit)

Analysis of variance			
Level	n	mean	st dev
OLS	6	1.4617	0.8403
ML	6	0.5650	0.4718
Pooled st dev = 0.6814			

```
95 % CI for mean (£)
--+--------+--------+--------+-----
              (--------*--------)
(--------*---------)
--+--------+--------+--------+-----
0.00     0.60     1.20     1.80
```

t-intervals	n	mean	st dev	se mean	95 % CI	
OLS studies	6	1.462	0.840	0.343	0.580	2.344
ML studies	6	0.565	0.472	0.193	0.070	1.060
all studies	12	1.013	0.801	0.231	0.504	1.522

Our studies: Thetford 1 (OLS study) mean consumer surplus = £1.07/person/visit
Thetford 2 (ML study) mean consumer surplus = £1.20/person/visit

3.3.2: ZTC Studies

The ZTC studies of Benson and Willis (1992) detailed in table 3.6 provide an interesting set of internally consistent studies. While the number of studies is considerably less than would normally be used for benefit transfer work our review (appendix 1) shows that these studies were conducted to a high standard and are not subject to the methodological and theoretical problems besetting reviewed ITC studies. However, the same review does show that the definition of the cost variable used in Benson and Willis' preferred 'Standard Model' [SM] is questionable. In an early paper the authors report findings from a sensitivity analysis across those definitions of the cost variable detailed in table 3.10.

Table 3.10: Cost specifications for standard and alternative models

Model	Assumptions	
	Travel Cost (p/mile)	Time Cost (% wage rate)
Standard model [SM]	33	43
Alternative [1]	33	25
Alternative [2]	33	0
Alternative [3]	Visitors estimate	43
Alternative [4]	8	0
Alternative [5]	8	43

Source: Willis and Benson (1989)

Justification for the various cost multipliers is considered in chapter 2. Clearly we will obviously get the order of consumer surplus estimates being [SM] > [1] > [2] and [SM] > [5] > [4] while other relationships are uncertain. Table 3.11 details estimates of consumer surplus per visit across forests calculated under each of the varying cost assumptions given in table 3.10. Here we can see a consistent ordering of results for all forests being [SM] > [1] > [2] > [3] > [5] > [4]. On inspection it is clear that varying time costs had relatively little impact upon consumer surplus estimates while varying travel costs had significant impacts. The authors point out that, a priori, time may be expected to have a more significant effect but that this may be diminished by its treatment as a subset of total costs (C_{ij}) rather than as a separate variable within the tgf.

Table 3.11: Consumer surplus per visit by forest under varying assumptions (£/visit; 1988 prices)

Forest district	[SM][2] Travel=33ppm Time=43%	[1] Travel=33ppm Time=25%	[2] Travel=33ppm Time=0%	[3] Travel=estimate Time=43%	[4] Travel=8ppm Time=0%	[5] Travel=8ppm Time=43%
New Forest	1.43	1.40	1.36	0.93	0.33	0.40
Cheshire	1.91	1.87	1.81	1.25	0.44	0.54
Loch Awe	3.31	3.21	3.05	1.92	0.73	1.00
Brecon	2.60	2.56	2.50	1.70	0.61	0.71
Buchan	2.26	2.22	2.16	1.67	0.52	0.63
Durham	1.64	1.77	1.73		0.54	
N. York Moors	1.93	1.87	1.84		0.59	
Aberfoyle	2.72	2.59	2.37		0.61	0.95
South Lakes	1.34	1.30	1.27		0.41	
Newton Stewart	1.61	1.57	1.53	1.24	0.36	0.45
Lorne	1.44	1.40	1.35	1.10	0.33	0.42
Castle Douglas	2.41	2.36	2.54		0.72	
Ruthin	2.52	2.47	2.40	1.72	0.58	0.70
Forest of Dean	2.34	2.19	2.13		0.69	
Thetford	2.66	2.62	2.55		0.76	

Weighted mean = £1.98[1]

Notes: 1.The authors often refer to a weighted mean cs/visit of £2.00 (Benson & Willis, 1992; page v.) for their standard model [SM]. However the actual figure (and that used for aggregation) is £1.983. We calculate that use of the higher figure would result in an overstatement of aggregate benefits in excess of £430,000.

Choice of the optimal model is problematic but clearly important. Unlike the ITC the degree of fit of the ZTC tgf may be affected by the choice and number of zones which will affect the already upwardly-biased (see chapter 2) fit statistic. The study authors advocate the use of consumer surplus estimates from the standard model [SM] in preference to alternative models on the following grounds (Willis and Benson, 1989; Benson and Willis, 1992):

i. They argue that respondents perceptions and statements regarding travel costs are based upon full rather than marginal (petrol only) cost per mile;

ii. They argue that respondents do not adopt differential costs toward recreation as opposed to non-recreation travel;

iii. Whilst respondents value the whole trip experience, the forest visit was valued proportionately more than the car journey, so that a positive time cost (of less than the full wage rate) can be justified, with the time cost used in the standard model being that most recently advocated by a government department (in this case the Department of Transport);

iv. "Given that entry fees at many National Trust, English Heritage and similar properties (which include gardens, parks, woodlands and forests) are closer to our higher estimate (£2.00), this figure seems realistic and plausible for car-borne forest visits of the kind studied in this project".

These justifications are open to some criticism. Arguments i and ii, which are similar, may well be true, however while respondents perceptions of travel cost well exceed pure marginal petrol costs of 8p/mile, the reported range of site average expressed travel costs (from 17.7p/mile to 27.1p/mile with a mean for all sites of 22.8p/mile) does not support the adoption of the 33p/mile assumption used in the 'standard model'. Table 3.12 gives details of respondents estimates of car running costs for the eight forest districts where this information was elicited.

Given the uncertainty surrounding the value of time, and in particular leisure time (see chapter 2) argument iii above is reasonable although one would not want to make such uncertainty the mainstay of any strong result. However, argument iv is open the criticism. Firstly the comparison of goods is invalid. Informal forest recreation is of the essence unpriced and indeed its public good nature may be endogenous to its value; comparisons with priced goods are therefore chalk and cheese. Secondly, if such a comparison between goods were valid, then the necessity of undertaking a three year TC study would disappear. Surely this is not an argument which the authors would push too strongly!

Table 3.12: Respondents estimates of car running costs

Forest district	Estimated car travel cost (p/mile)	confidence interval (±) (p/mile)	Sample size
Brecon	20.85	9.31	47
Buchan	23.77	11.02	135
Cheshire	21.77	7.51	128
Loch Awe	17.74	11.85	38
Lorne	27.08	19.36	119
New Forest	21.02	14.45	266
Newton Stewart	25.21	15.75	150
Ruthin	21.92	10.91	61
All sites	22.79	13.91	944

Source: Willis and Benson (1989)

While we can accept the authors choice of functional form, it would seem that their choice of the 'standard model' [SM] results as the most accurate is less defensible. Indeed, following the authors own reasoning (see argument i above), it would seem that the most logical model is that using time costs valued at 43% of wage rates (as this is a government recognised figure) and travel costs calculated as visitors perceived costs (average of 22.8p/mile) i.e. model [3] in table 3.11. One problem with this approach is that data for such an analysis was only collected at certain sites. However, an approximation can be derived by first calculating the ratio of consumer surplus results for models [3] and [SM] for these sites. The weighted average of this ratio can then be used to extrapolate for the remaining other seven sites. Table 3.13 calculates this weighted ratio ([3]/[SM]) as 0.690 and uses this to estimate consumer surplus per visit at the seven sites where perceived costs were not elicited. These results together with those of model [3] from consumer surplus estimates for all sites under the assumption of perceived travel costs and 43% wage rate time costs and are recorded in table 3.13 as model [3*]. An all sites weighted average consumer surplus was then calculated as being £1.48 per visit. We would argue that this represents a more defensible result than the weighted average of £1.98 obtained from the [SM] model and preferred by Willis and Benson[13].

Table 3.13: Calculation of the whole sample weighted mean consumer surplus per visit for model [3] (producing model [3*])

Forest district	Sample size	% of total sample	% of model [3] sample	CS/visit [SM] (£)	CS/visit [3] (£)	Ratio [3]/ [SM]	CS/visit [3*] (£)
New Forest	316	6.59	16.97	1.43	0.93	0.650	0.93
Cheshire	324	6.76	17.40	1.91	1.25	0.654	1.25
Loch Awe	56	1.17	3.01	3.31	1.92	0.580	1.92
Brecon	241	5.03	12.94	2.60	1.70	0.654	1.70
Buchan	201	4.19	10.79	2.26	1.67	0.739	1.67
Durham	481	10.03		1.64			1.13[2]
North York Moors	387	8.07		1.93			1.33[2]
Aberfoyle	1148	23.94		2.72			1.88[2]
South Lakes	322	6.71		1.34			0.92[2]
Newton Stewart	213	4.44	11.44	1.61	1.24	0.770	1.24
Lorne	201	4.19	10.79	1.44	1.10	0.764	1.10
Castle Douglas	66	1.38		2.41			1.66[2]
Ruthin	310	6.46	16.65	2.52	1.72	0.683	1.72
Forest of Dean	276	5.75		2.34			1.61[2]
Thetford	254	5.30		2.66			1.84[2]
Total	4796	100.00					
Model [3] total	1862		100.00				
Weighted mean				1.98		0.690[1]	1.48[3]

Notes:
1. Calculated by multiplying the ratio [3]/[SM] by the decimal % of model [3] sample column and then finding the (weighted) mean.
2. Calculated by multiplying the site [SM] CS/visit for sites where perceived costs were elicited by the weighted average of the ratio [3]/[SM] to 7 decimal places (0.6901678) and then rounded.
3. Calculated by weighting the site [3*] CS/visit by its decimal % of total sample (across all sites). Calculated to 7 decimal places (1.481469) and then rounded.

Clearly the results given in table 3.13 are far from an ideal meta-analysis of benefit transfer values. Furthermore, rather than producing a benefit transfer function linked to site features, etc. we have only produced a single mean estimate of recreational value. This is, we freely admit, far from ideal. However, as our reviews of various papers[14] have shown, the

[13]Interestingly, following this adjustment, the authors agreed (*pers. comm.*) that their original estimates had used somewhat upper bound assumptions.

[14]Very few papers have attempted to address the issue of attribute rather than site valuation, even though such work is vital if successful and sensitive benefit transfers are to be undertaken. Even those studies which have attempted such disaggregations have not been successful in so doing (see our review of Hanley and Ruffell, 1991, 1992).

state-of-the-arts in UK evaluation studies is still in its formative stages. This being so we feel that the estimation of mean values does provide useful - estimates of the magnitudes of recreation value which can, with appropriate caution, be used for benefit transfer work. As such, our reviewed-ZTC study mean of £1.48 provides a defensible starting point for our wider research.

3.3.3: CV Studies

Our cross analysis of UK CV studies of woodland recreation studies best conforms to the benefit transfer approach of Smith and Kaoru (1990) and Walsh et al., (1992) although (as with these) it still falls short of an ideal meta-analysis. Our review shows that these CV studies can be categorised into three types:

(i) per household capitalised valuations;
(ii) per person per annum valuations;
(iii) per person per visit valuations.

In section 3.2.2 we raised serious questions concerning the validity of those type (i) studies. Furthermore section 3.2.3 showed that there have been insufficient type (ii) studies to justify any cross-study analyses. Consequently our attention has been focused upon those type (iii) studies (section 3.2.3.1) yielding per person per visit value. Table 3.7 details 9 studies yielding 48 evaluation estimates. This is considerably less than those used by Smith and Kaoru (77 studies of which 35 used to yield roughly 400 estimates) or Walsh et al., (120 studies used yielding 287 estimates of which 129 used the CV method). This underlines the difference in available, comparable studies in the US and UK and reinforces our opinion that benefit transfer in this country is currently premature. The analysis we conducted here was therefore intended to be illustrative rather than definitive.

One early consideration concerned the extent to which our Thetford 1 studies were compatible, or not, with the others detailed in table 3.7. We were concerned that the use of two types of payment card may make it impossible to incorporate these results into our benefit transfer study. An analysis of variance suggested that these fears were well founded (see details in chapter 4) and these two results were excluded from our wider analysis.

Our remaining database of evaluation estimates yielded the following simple explanatory variables:

WTP	=	Study mean willingness to pay (£/person/visit)
OPTION	=	1 if the study asked WTP for use + option value; 0 if the study asked WTP for use value alone
ELICITAT	=	Elicitation method (categorical variable): 1 = open ended; 2 = iterative bidding; 3 = payment card; 4 = dichotomous choice
OE	=	1 if open-ended elicitation method; 0 if other elicitation method
AUTHOR	=	Authorship (categorical variable): 1 = Hanley and Ruffell; 2 = Bishop; 3 = Willis and Benson (1989); 4 = Hanley (1989); 5 = Willis et al., (1988); 6 = Bateman; 7 = Whiteman and Sinclair.

Following Glass et al., (1981) an early concern[15] was to ensure the comparability of studies. A number of reviewed studies had been excluded from table 3.7 due to design, implementation or gross reporting problems (see appendix 1). To some extent further problems may have been identified by analysis of the AUTHOR variable which identified individual study designs. Although a generalised linear model analysis did reveal some differences, these were highly correlated with the OPTION and OE variables and the AUTHOR variable had to be omitted from further analysis. Analysis of unusual design effects was therefore conducted by identifying outliers (as detailed below).

Clearly the variables ELICITAT and OE cannot be included within the same model. Analyses of variance showed that the numbers in categories 2, 3 and 4 of the ELICITAT variable were too small (1, 2 and 1 respectively) to allow for meaningful individual treatment. However, when these categories were amalgamated to form the OE variable, a highly significant difference (5% level) between results from these and the open-ended studies was observed. Details of this latter analysis are given in table 3.14.

[15]Our first concern in compiling our data-base was to exclude those studies which we felt were of a poor design standard (see appendix 1 for details).

Table 3.14: Analysis of variance in WTP as a result of the OE variable

Analysis of variance				95 % CI for mean WTP[1]
OE level	n	mean	st dev	---------+--------+--------+--------
0	4	1.3535	1.2945	(---------*--------)
1	42	0.7571	0.0819	(--*--)
Pooled st dev = 0.2862				--------+--------+--------+--------- 0.90 1.20 1.50

Source	df	SS	MS	F	p
OE	1	1.2945	1.2945	15.81	0.000
error	44	3.6029	0.0819		
total	45	4.8974			

Notes: 1. Based on pooled st dev. F and p values are calculated as per the default method used by the Minitab statistics package (see note to Table 4.21 subsequently).

Following these preliminary analyses we concluded that the most conservative approach was to investigate a simple model of WTP relating it to just the OPTION and OE variables. Table 3.15 details results from our initial findings from such a model and statistically unusual observations.

Studying the unusual observations from our initial regression model, we have no problem with those observations with a large influence as these all relate to the non-OE studies. However, there are two clear outlier in the form of observations 13 (Bishop, 1992; OE use + option value for Whippendell Wood) and 32 (Hanley, 1989; OE use value for Aberfoyle). Further analysis confirmed these to be highly unusual results indicating significant differences in design methodology from that adopted by other authors. Of the two, the Hanley (1989) OE use value result is the most unusual. In our review of this study (see appendix 1 for details) we argue that the approach used in this study was likely to lead to a significant overstatement of WTP. This conclusion appears to be supported by the above analysis. Both of these results were deleted from our model of WTP studies which was then re-estimated. Results for our best fitting model are given in table 3.16[16].

Table 3.15: Initial multiple regression model of reviewed woodland CV studies (£/person/visit values)

Dependent variable = study mean WTP (£/person/visit)

Predictor	Coef	Stdev	t-ratio	p
Constant	1.3525	0.1241	10.90	0.000
OPTION	0.30720	0.07801	3.94	0.000
OE	-0.7197	0.1336	-5.39	0.000

s = 0.2482 R^2 = 45.9% R^2(adj) = 43.4% n = 45

Unusual observations

Obs.	Option	WTP	Fit	Stdev.Fit	Residual	St.Resid
7	0.00	1.1400	1.3525	0.1241	-0.2125	-0.99 X
8	0.00	1.3100	1.3525	0.1241	-0.0425	-0.20 X
9	0.00	1.4100	1.3525	0.1241	0.0575	0.27 X
13	1.00	1.4600	0.9400	0.0602	0.5200	2.16R[1]
32	0.00	1.5300	0.6328	0.0496	0.8972	3.69R[2]
33	0.00	1.5500	1.3525	0.1241	0.1975	0.92 X

R denotes an obs. with a large st. resid.

X denotes an obs. whose X value gives it large influence.

Notes: [1] Bishop (1992) OE use + option value for Whippendell Wood

[2] Hanley (1989) OE use value for Aberfoyle

[16]Rudimentary functional form analysis confirmed the linear form of the best fit model.

Table 3.16: Final multiple regression model of reviewed woodland CV studies (£/person/visit values)

Dependent variable = study mean WTP (£/person/visit)

Predictor	Coef	Stdev	t-ratio	p
Constant	1.3525	0.09634	14.04	0.000
OPTION	0.31208	0.06219	5.02	0.000
OE	-0.7571	0.1041	-7.28	0.000

R^2 = 61.1%R^2(adj) = 59.2%n = 43

Analysis of variance on WTP

SOURCE	DF	SS	MS	F	p
Regression	2	2.3886	1.1943	32.17	0.000
Error	41	1.5222	0.0371		
Total	43	3.9108			

SOURCE	DF	SEQ SS
OPTION	1	0.4234
OE	1	1.9652

A number of interesting observations arise from table 3.16. The overall fit of the model is good (given that we are dealing with socioeconomic data) with about 60% of total variation explained. The strongest explanatory variable is the constant, a finding which accords with many other CV bid functions both from our own (e.g. Bateman et al., 1992) and others research. The strength of the constant is interesting and may, we believe indicate a disturbing determinant of stated WTP. It may well be that a major factor affecting WTP responses is individuals perceptions of a socially appropriate payment level. This 'social norm' may be linked, quite properly, to perceptions of existence value i.e. the value of the asset as a public good separate from the valuers personal use. However, it may also be linked to less valid influences such as (and particularly in the case of an entrance fee payment vehicle) the respondents experience of fees at comparable (open-air) attractions, e.g. car parking fees[17]. Figure 3.1 illustrates how such a regression constant may be formed.

Figure 3.1: Formation of the WTP regression coefficient

Social Norm — Experience of Fees

Value of WTP Regression Constant

The extent to which these 'social norm' and 'fee experience' factors influence WTP responses is uncertain and would require specific investigation. However, the potential influence of such factors upon the validity of CV estimates marks this out as an area deserving of further research.

All the observations were from on-site users of forest resources. These users can express a variety of values[18]. We feel that, where the question of valuation types is not explicitly raised, it is most likely that respondents WTP statements are dominated by their use value (i.e. users use value). However, as discussed, several authors have attempted to broaden this value definition to include option values. This has been done by asking respondents, after their initial WTP response, to state how much they would be WTP in addition to secure future use of the site. Such questions are dummied by the OPTION variable above. As can be seen, responses to such questions result in significantly higher WTP sums.

We have not asked such questions in our studies as we are sceptical of their validity. Respondents have just stated their use value WTP and some anchoring is likely to occur. Equally importantly we feel that such questionnaire structures put the respondent under a psychological obligation to 'improve' on their previous WTP response. Such questions may, we argue, make respondents feel that their previous WTP bid was inadequate. It is also unclear whether or not such questions will invoke concerns regarding continued access for others to the resource; bequest values; etc. In all we feel that such questions elicit a fairly meaningless higher response.

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[17]Interestingly, since completion of the Thetford 2 study (detailed in chapter 4), the Forestry Commission has introduced a car park fee of 50p at Lynford Stag (open air walks area) and £1 at High Lodge (open air walks plus visitor centre), amounts which are well within our estimates of per person recreational value.

[18]Subsumed within the catchall concept of Total Economic Value (see chapter 1).

The regression equation also shows a significant relation between WTP response and elicitation method such that responses elicited using OE techniques are significantly lower than those obtained by other methods. This echoes our findings from earlier research (Bateman et al., 1993). We have shown that, in the absence of highly developed questionnaire techniques, OE methods may provide a better estimate[19] of WTP than do other approaches[20]. Given this and our concerns regarding the 'use + option value' measures, we have less reservations[21] about predictions of use value elicited using OE techniques than we do about the other values implied by our best fitting model (table 3.16). The fitted mean values estimated from this model are summarised in table 3.17. Accordingly our preferred benefit transfer estimate from our database of reviewed CV studies of per person per visit valuations is that for use value (alone) estimated via OE techniques, namely £0.60/person/visit.

Table 3.17: Predicted users WTP response for a variety of CV questionnaire types (£/person/visit)

Value type	Elicitation Method	
	OE	Other
Use Value	0.60	1.35
Use + Option Value	0.91	1.66

3.4: CONCLUSIONS

Our review of UK monetary evaluations of woodland recreation suggests that such research, while arguably out of its infancy, is still far from mature. In particular the body of consistent, high quality papers necessary for advanced benefit transfer, meta-analysis does not exist to date (although it is arguable whether this is even strictly true of the more advanced

[19]Here we define a better estimate as one which minimises elicitation bias. An error from formulated WTP may still remain (see chapter 2).

[20]See discussion of relevant non-forestry research at start of chapter 4 and Bateman et al., forthcoming.

[21]Note the phraseology; we do not claim that the OE/use value estimate is correct, just that it is likely to be less biased than other measures.

US literature). Consequently we have had to conduct fairly simple cross-study analyses. Even these have only been feasible upon per person per visit ZTC and CV studies, the former yielding a best estimate of £1.48 and the latter giving a value of £0.60. These provide magnitude estimates permitting a simple sensitivity analysis. However, these estimates are admittedly crude, being insensitive to site and locational factors. We attempt to address these factors in our own work which examines forests with common recreational features and explicitly models the locational issue through spatial prediction of the number of arrivals (if not variation in individual values). This work also provides new valuations of woodland recreation which, in certain cases, we prefer to those reviewed in this chapter.

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Chapter 4: Recreation: New Valuation Studies

4.1 INTRODUCTION

This chapter presents our own relevant recreation evaluation work using the CV and TC methods. This is subdivided into studies of woodland, and studies which looked at non-forest resources but derive results which are of direct relevance to this research.

The chronology of our work is important as we feel that the robustness of study design and analysis improved considerably over the course of this research. In defence of our early studies these adhered closely to contemporary UK practice in valuation work. However, subsequent work introduces more advanced techniques from US studies allowing for more sophisticated analysis. Indeed, in later work we have attempted to exceed the specification of such US studies.

This chapter does not, as might be expected, end by drawing together general conclusions across these studies. Instead chapter 5 brings together both these studies and those reviewed previously to provide an overall assessment of findings. However, we do feel that each of the studies discussed here addresses different theoretical and empirical problems. We therefore provide brief commentary and conclusions within our discussion of each of the studies presented in this chapter.

4.2 RELEVANT NON-WOODLAND RESEARCH

In collaboration with others we have concluded a variety of non-forestry recreation evaluations during the course of this research[1]. Of these, the group of studies of most direct relevance to this research was our CV analyses of the recreational and environmental preservation value of the Norfolk Broads (Bateman et al., 1992, 1993, 1995a/b and forthcoming; Bateman and Bryan, 1994; Bateman and Langford, forthcoming a; Langford and Bateman, 1993; Langford, Bateman and Langford, 1994, 1996). Findings from this work strongly influenced our design of subsequent CV woodland studies in that they answered two

[1]Other CV studies include studies of recycling in Norfolk and Northern Ireland; waterside recreation at Rutland Water was recently (for the NRA); eutrophication in the Baltic Sea (jointly with CSERGE, Harvard Institute of International Development, the Beijer Institute (Stockholm) and Warsaw University) and laboratory testing of part-whole and WTP/WTA disparities (with Professor Robert Sugden, UEA). Other TC work includes a study of the Norfolk Broads.

important questions which we had previously identified as problem areas for empirical analysis: first, what payment vehicle should be used and; second, what elicitation method to adopt[2].

4.2.1 PAYMENT VEHICLE EFFECTS

As indicated in chapter 2, one of the questions we wished to address in our research was how respondents may react to changes in the method of payment used. Prior to the main Norfolk Broads survey, a smaller sample of 433 respondents was collected through face-to-face interviews with users of Broadland. Following Boyle and Bishop (1988), it was decided that in the absence of any a-priori expectations, this initial survey should be undertaken using an OE elicitation method and that three payment vehicles should be tested as follows:

1. An unspecified charitable donation (DONATE).
2. Payments to a hypothetical charitable fund specifically set up to facilitate flood defence work in Broadland (FUND).
3. Payments via direct taxation (TAX).

Other alternatives were considered to lack credibility for this particular study. Specifically entrance fees were, given the nature of the resource (large area; considerable resident population; no UK precedent), not thought to be credible.

Table 4.1 details WTP and related results from this study across each payment vehicle.

Analysis of table 4.1 reveals the reasons for rejecting both the DONATE and FUND vehicles. The DONATE vehicle suffered disproportionately from zero WTP bids (46.5%) compared to either of the other vehicles. It was felt that the vague definition of this vehicle led respondents to be uncertain that their donations would be effectively used. In short such a vehicle did not engender credibility in the hypothetical market and was therefore rejected.

[2]Further design decisions can also be attributed to this work. For example, response rate problems in our mail survey of non-users of the Broads led to a subsequent decision to adopt face-to-face interviewing techniques in our woodland studies.

Table 4.1: Norfolk Broads study: payment vehicle analysis

Payment vehicle	N	WTP=0 (number)	WTP=0 (%)	WTP>500 (number)	WTP>500 (%)	mean WTP (£)	median WTP (£)	trimmed mean (£)
DONATE	157	73	46.5	0	0	25.60	10.00	20.34
FUND	65[1]	15	23.1	2	3.1	47.60	10.00	22.00
TAX	211	25	11.8	10	4.7	89.22	40.00	65.06

Payment vehicle	st. dev.	coeff. of variation (%)	s.e. mean	min. value (£)	max. value (£)	lower quartile (£)	upper quartile (£)
DONATE	39.81	156	3.18	0	250	0	50
FUND	140.70	296	17.40	0	1000	1	50
TAX	144.95	162	9.98	0	1000	10	100

[1] Excludes one outlier (see text).

Mean bids for the FUND vehicle were heavily upwardly biased by the presence of a single extreme outlier bid of £10,000 which was omitted[3]. Table 4.1 shows that the FUND vehicle still performs badly in terms of high zero bid rate (23.1%) and also performs markedly worse than either the DONATE or TAX vehicles in terms of bid. The FUND vehicle was therefore also rejected.

The TAX vehicle produced by far the lowest zero-bid rate (11.8%) almost half that of FUND and one quarter of the DONATE vehicle. The TAX vehicle also performed better in terms of bid variability than the FUND vehicle and about as well as the DONATE vehicle. As no vehicle produced excessive evidence of strategic bidding (large numbers of unreasonably high bids) this was not deemed a problem and thus the TAX vehicle was the preferred choice. It was also favoured by the fact that, if flood defence works were to be built, such works would in reality be paid for out of taxes rather than trust-fund donations. The TAX vehicle therefore had the advantages of realism and immediate applicability, an advantage that also applied to our forestry studies.

[3]After questioning by the interviewer this particular bid was judged not to be strategic behaviour because the respondent was actually a major landowner within the Broads with an annual income from commercial Broadland recreation exceeded £300,000, an income which would be put at risk by flooding in Broadland. As such the respondent was expressing a categorically different type of value to the rest of the sample and was therefore omitted from the analysis reported in table 4.1.

All respondents were asked why they had responded in the way they had. Many of those presented with the FUND (and especially DONATE) vehicles commented that they were not confident that payments via such vehicles would be fully channelled towards preservation work (trust funds were not to be trusted!). Furthermore many of those responding to the TAX vehicle commented that, while they disliked paying extra taxes, they had confidence that such money would be spent efficiently upon any flood defence scheme[4].

One potential criticism of the TAX vehicle is that, while most respondents see a TAX sum as applying to all taxpayers, others may be unsure about this. Furthermore other respondents may currently be non-taxpayers. This latter criticism can to some extent be countered by pointing out that the WTP question refers to an absolute tax increase rather than a proportional increase on existing payments. Overall it was felt that the statistical advantages and realism of the TAX vehicle outweighed any disadvantages. Consequently it was concluded that future research on per annum WTP for woodland should use a tax based payment vehicle[5].

4.2.2 ELICITATION EFFECTS

In chapter 2 we presented a variety of, in some cases conflicting, economic and psychological arguments regarding the effect which changes in the elicitation method may have upon WTP responses. Differing context and respondent cognition and motivation may lead to stated WTP being either in excess of, or below, formulated value. We therefore saw the investigation of such elicitation effects as a major objective of our research. Fortunately, significant funding for such work was obtained from the NRA (although with the proviso that the study had to focus upon the Norfolk Broads) allowing a series of large sample tests across elicitation methods. The study undertaken is the largest CV experiment in Europe to date and is comparable with major US studies. It is also one of only a handful of studies worldwide to conform to the US NOAA "Blue Ribbon Panel" guidelines drawn up by Kenneth Arrow, Robert Solow and others regarding the conduct of CV studies (Arrow et al., 1993).

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[4]Another issue may be that as the TAX vehicle involved money being taken away before it is received then individuals may find this less 'painful' than the FUND/DONATE vehicles which involve visable losses.

[5]Clearly such a vehicle is inappropriate for our per visit analyses; see subsequent discussion.

4.2.2.1 The elicitation methods

The Norfolk Broads study investigates three WTP elicitation methods[6]: open-ended (OE); dichotomous choice (DC); and iterative bidding (IB). The OE approach requires a separate sub-sample but the DC and IB studies are linked in a way so as to allow a further 'multi-level modeling' (MLM) dichotomous choice analysis to be performed as follows:

1. Prior to all (OE/DC/IB) WTP questions, respondents were asked whether or not they were willing to pay some amount for the good in question (the 'payment principle'). This legitimised a negative response which may have been inhibited by going straight to the WTP question. Answers to this question are usually analysed separately from responses to WTP questions (as the latter involves a subsample of those answering the payment principle question). However, MLM techniques allow this to be analysed as the first level of the full set of WTP responses.
2. Respondents who answer the payment principle question positively are then presented with a randomly selected initial bid level which they are asked whether or not they would be willing to pay. The binary answer to this question forms the DC response[7].
3. All such respondents are then given a supplementary dichotomous question determined by their initial DC response. If, for example, a respondent agreed to pay an initial bid of £X, this amount was doubled in the second round question while it would be halved if the initial response was negative. This forms the double-bound dichotomous response[8] (2DC).
4. This process is then iterated again to produce a 3DC response.
5. Finally respondents were asked to state, in an open-ended manner, their maximum WTP. This formed the IB response, so called because it is the final answer from the iterative process.

Figure 4.1 illustrates the possible bidding pathways arising from just one initial DC bid level (here £100).

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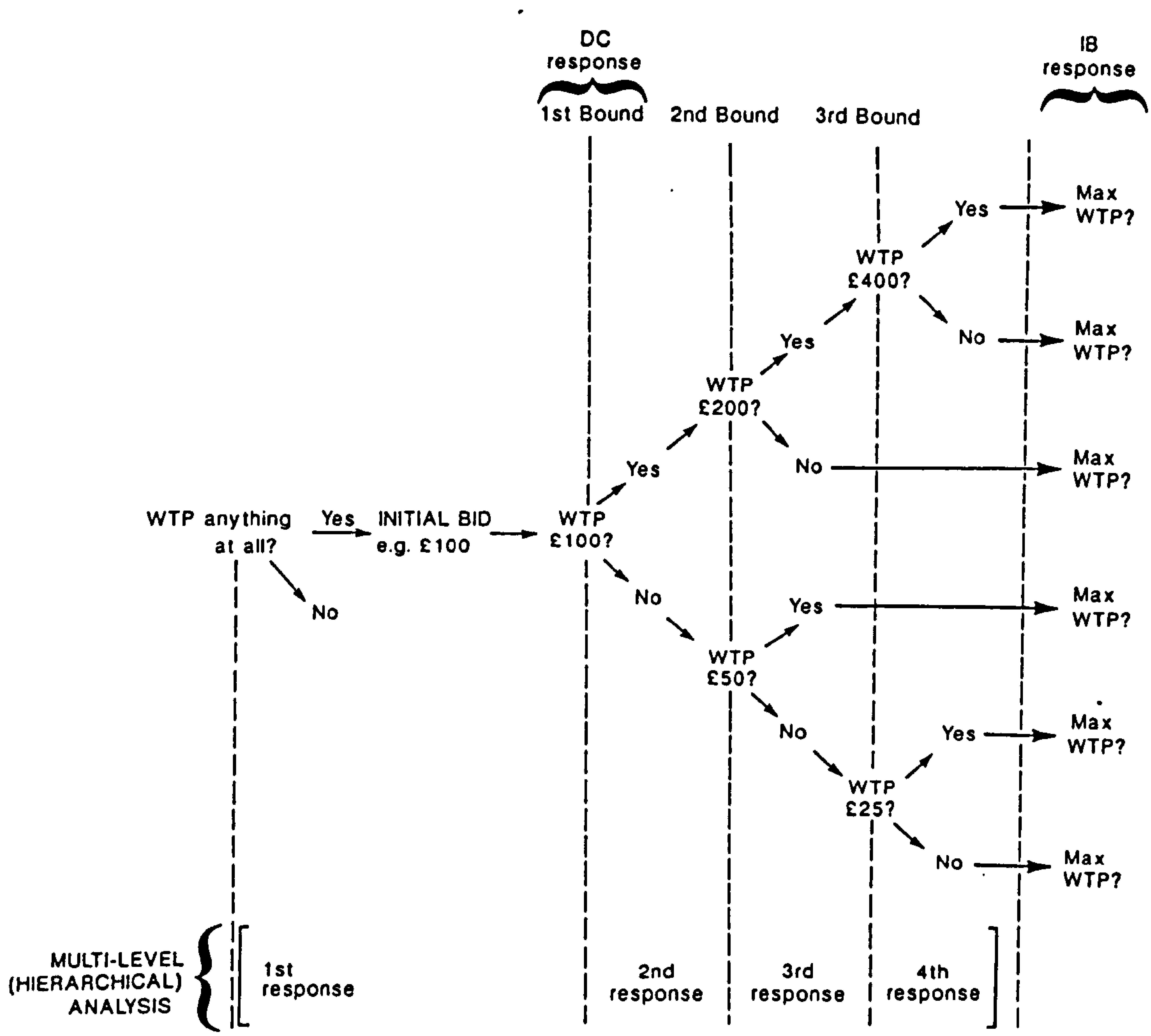
[6]Further details of the operation of each method are given in chapter 2.

[7]Details regarding determination of the number and absolute value of DC bid levels are given in Bateman et al. (1993). It should be emphasised that a variety of other analyses were conducted as part of this research as detailed in Bateman et al. (1992).

[8]Following the nomenclature of Hanemann et al. (1991).

Figure 4.1: DC, IB and ML responses arising from a single initial bid level



Source: Bateman and Bryan (1994)

4.2.2.2 Analysis of data

The analysis of WTP responses from the OE and IB formats is simple as both yield continuous variables for which calculation of means is trivial. Although both are truncated at zero, analysis of distributions indicated that least-squares regression analysis of bid functions was not inappropriate for these formats. Analysis of the binary DC (initial bid level response) data was also relatively straightforward. Here bid curve estimation via logit (or similar) analysis is required with mean WTP being derived from the area under the bid curve (cumulative probability distribution (CPD) function). Further details of OE, IB and DC analyses are given in Bateman et al. (1993, 1995a) and Langford and Bateman (1993). Analysis of the multi-level data is somewhat more complex. Hanemann et al. (1991) in their double-bounded dichotomous choice experiment, employ a multinominal logistic design to estimate likelihoods for the probabilities of each of the possible set of responses (i.e. an extension of our DC analysis). However, such an approach becomes almost infeasibly complex when set against the diversity of possible responses in a triple-bounded design. Therefore we applied the hierarchical, multilevel statistical techniques developed by Goldstein (1987) in the context of educational research. A considerable advantage of a MLM approach is that the prior question concerning the principle of paying anything at all can be analysed as part of the bid function rather than separately as with all other elicitation formats. Full details of this analysis are given in Langford, Bateman and Langford (1994, 1996).

4.2.2.3 Results and discussion

i. The OE Experiment

In total 862 interviews were completed using the OE elicitation method. Of these some 131 respondents answered 'no' to the payment principle pay question. All such respondents were then asked to state why they had given such an answer. The most common reasons for non-payment was related to income and existing commitments (almost 40% of non-payers, equivalent to 6% of the total OE sample) followed by the pure free-rider reply that, although the area was valued, someone else (e.g. the government) should pay (almost 25% of non-payers, equivalent to 4% of the total OE sample). Whilst income constraints pose no problem here, the free-riding effect does point to a possible downward bias in the OE estimate of WTP. More importantly this small group of extreme free-riders may indicate the existence of a larger group of respondents who, whilst still stating some non-zero sum, nevertheless reduced their stated WTP below true WTP as a result of the free-rider incentive. However, attempts to quantify such a strategy would have required a significant extension to the questionnaire (and possibly laboratory-type controls) and were consequently not undertaken[9].

Evidence of 'protest bidding', in the sense of a refusal to participate in the valuation

[9]It is interesting to note that recent reviews have indicated that free riding behaviour may result in a reduction of stated WTP to (very approximately) between 60-95% of true WTP depending upon the strength of the incentive to free ride. See chapters 6 and 7 of Mitchell and Carson (1989) and Milon (1989).

process, was conspicuously absent. The possibility of such a response was directly catered for by listing a refusal to value the Broads as an explicit option amongst reasons for refusing to pay. However, only 30 respondents (1% of the total OE + DC/IB sample) gave this as their reason for refusal. This finding strongly contradicts the assertion by some commentators that CV studies are pervasively invalidated by the prevalence of protest bids (Sagoff, 1988).

Alongside evidence of free-riding, other respondents in the OE sample appeared to exhibit strategic overbidding. Table 4.2 details univariate OE WTP statistics for a variety of upper tail truncation points. Mean WTP for the entire OE sample of 846 respondents was £67.19 (95% CI = £59.53; £74.86). However, omission of just the single highest bid (0.11% of the OE sample) caused OE mean WTP to fall to £65.79 (a reduction of over 2%). Similarly truncating the top 1% of bids causes a reduction in the mean of nearly 10%. In themselves such statistical effects are not conclusive proof of strategic overbidding as a skewed distribution may simply reflect the socioeconomic and preference characteristics of the sample. However, upon inspection it was found that the sums stated by those at the upper tail of the bid distribution appeared infeasible given the ability of these respondents to pay. Several of the highest bidders stated WTP sums which exceeded their entire annual expenditure upon all recreational and environmental goods (in some cases by a factor of 5). We therefore conclude that there is strong evidence for a degree of strategic overstatement by a small number of respondents in the OE experiment.

Validity testing was applied to all three elicitation methods following the criteria set out by Mitchell & Carson (1989). Content validity was, in the main, carried out prior to the survey and consisted of a number of meetings with recognised authorities in the fields of economics, marketing, social surveys and psychology. These consultancies addressed all aspects of the study with particular emphasis on the design of the questionnaire, associated information and survey sampling strategy. Criterion validity testing (comparison with actual WTP for the good) was not feasible and therefore a major effort was made to establish construct validity (i.e. testing whether results conformed to expectations). One simple approach, comparing mean WTP with that of other studies (convergent validity), was only feasible for the OE study as other formats have had few applications in the UK to date. Results from the OE experiment were contrasted with those from 28 comparable UK use-value studies[10]. This analysis showed results to be logically related according to two factors:

i) the number of adequate substitute sites available;

ii) the magnitude of the proposed change in provision.

Table 4.2: Truncation effects - open ended WTP study[1]

No. of upper tail truncated	0	1	8	42	84	126	168	211
% of upper tail truncated	0%	0.1%	1%	5%	10%	15%	20%	25%
N	846[2]	845	838	804	762	720	678	635
Mean WTP[3]	67.19	65.79	60.89	46.76	37.38	32.57	28.39	25.54
Median WTP	30.00	30.00	30.00	25.00	25.00	20.00	20.00	12.00
St. Dev.	113.58	106.10	90.08	55.19	38.64	33.69	30.10	24.41
S.E. Mean	3.91	3.65	3.11	1.95	1.40	1.26	1.16	0.97
Maximum Bid[4]	1250.00	1000.00	500.00	250.00	150.00	100.00	100.00	100.00
Lower Quartile	5.00	5.00	5.00	5.00	5.00	2.13	2.00	1.00
Upper Quartile	100.00	100.00	100.00	60.00	50.00	50.00	50.00	50.00

Notes: [1] All rows, except the upper three, are measured in £'s
[2] Total sample of 862 interviews included 16 incompleted questionnaires (omitted from calculation of mean)
[3] Includes, as zeros, those who refused to pay anything at all
[4] Minimum bid = zero throughout.

Most other UK studies have looked at sites with some or many substitutes, facing relatively marginal changes in provision. Accordingly the fact that this study estimates a mean WTP value higher than most others seems logically correct.

The theoretical validity of OE responses was examined via estimation of the bid function. A full range of explanatory variables was investigated. Functional form was a-priori, uncertain (although linear forms were theoretically undesirable), but an initial analysis indicated that a high degree of overall explanation was unlikely to be achieved (a characteristic of OE studies). Therefore detailed (e.g. Box-Cox) analysis of functional form was by-passed in favour of using standard forms. The best model was provided by a double

[10]Full results are given in Bateman, Willis and Garrod (1994).

log form which is reported in equation (4.1). This model narrowly outperformed a semi-log (dependent) form which contained the same explanatory variables.

$$\underset{}{LWTP(OE)} = \underset{(0.22)}{0.1934} + \underset{(3.32)}{0.2920}\ LINC + \underset{(4.15)}{0.2695}\ RELAX + \underset{(3.93)}{0.2473}\ ENV \tag{4.1}$$

where: LWTP(OE) = Natural log of open ended WTP response
LINC = Natural log of respondents income (continuous variable)
RELAX = 1 if respondent often visits area to relax/enjoy scenery (=0 otherwise)
ENV = 1 if respondent is a member of an environmental group (=0 otherwise)

R^2 = 5.29%
Total d.f. = 800[11]
Figures in brackets are t-statistics.

The explanatory variables given in equation (4.1) are all significant at the 99% level, while no further variables were significant at even the 95% level. The major feature of this 'best model' is its very poor overall degree of explanatory power[12], which although more extreme than usual in this case, is a characteristic trait of many OE studies. Therefore, while the logical ordering of mean responses observed across studies indicates that economic theory is adequate to explain results at such a level, the poor performance of the model given in (4.1) suggests that further consideration of the motivations underlying individual responses is required here (see below).

ii. <u>The DC experiment</u>

As with the OE survey, those interviewed using the DC/IB questionnaire were asked, prior to the WTP questions, whether or not they were willing to pay any extra taxes. In total 240 of the 2070 DC/IB respondents answered 'no' to this question (11.6%). Tests showed there to be only one significant predictor of a positive response to this question, namely membership of an environmental group[13]. All respondents who refused to pay any extra taxes were asked to specify a reason why. As before, the most common reasons involved income constraints and existing commitments (33% of non- payers; 3.9% of the total sample)

[11]Equation (4.1) omits all responses for which information on any explanatory variable was missing.

[12]To ensure that no errors had been made, statistical analysis was carried out independently at the University of East Anglia and at the University of Newcastle-upon-Tyne. Both analyses confirm the weak explanatory power of the 'best' model.

[13]Significant at $\alpha = 1\%$. No other significant factors at $\alpha = 5\%$.

closely followed by the pure free-riding response (31.7% of non-payers; 3.7% of the total sample)[14]. Analysis failed to reveal any significant factors determining the reason for non-payment.

Those respondents who indicated that they were prepared to pay at least some amount were then asked to pay one of the bid levels, selected at random. The mean DC WTP is calculated by integrating the CPD function between appropriate truncation limits. Accurate estimation of the bid function is therefore vital, because an incorrectly fitted function will give a spurious estimate of the mean. Both linear and log models were tested using both logit and probit link functions. Log models gave a markedly better fit than linear specifications. The choice between link functions was more difficult as both logit and probit approaches performed similarly well[15]. However, a log-logistic model gave a marginally better fit and as this has been used extensively elsewhere it was preferred for further analysis. In all cases the most remarkable feature of the estimated models was the very high explanatory power of the bid level in determining WTP response. Equation (4.2) presents the log-logistic model resulting from the single explanatory variable LBID; the natural logarithm of the bid level (£) presented to respondents.

$$\mathrm{LOGIT}\ (\pi_i) = \underset{(-19.74)}{-4.932} + \underset{(18.39)}{0.9939}\ \mathrm{LBID} \tag{4.2}$$

Deviance change	=	-594.4
Residual deviance	=	1325.7
d.f.	=	1624

Figures in brackets are t-statistics

where: $$\mathrm{LOGIT}\ \pi_i = \ln\left[\frac{\pi_i}{1-\pi_i}\right]$$

π_i = probability of an individual saying 'no' to the bid level[16]

[14]Note that as this question was asked prior to any WTP question, this response does not refute the earlier suggestion that DC formats may inhibit free-riding relative to OE approaches.

[15]Full details in Bateman et al. (1993).

[16]Readers should be aware that this means that 'positive' relationships (e.g. between WTP and income, etc) will have a negative sign and vice versa.

As can be seen from equation (4.2), a log logistic model with the single explanatory variable LBID fits the dichotomous choice dataset extremely well[17]. Further explanatory variables were then added to this model in an attempt to improve the fit[18]. The best log-logistic model is given as equation (4.3).

$$\begin{aligned} \text{LOGIT}(\pi_i) = & \underset{(-6.23)}{-3.736} + \underset{(18.40)}{1.026}\ \text{LBID} - \underset{(-1.34)}{0.0907}\ \text{LINC} \\ & \underset{(-3.35)}{-0.5888}\ \text{BOAT} - \underset{(-2.58)}{0.3756}\ \text{RELAX} - \underset{(-2.22)}{0.3126}\ \text{ENV} \end{aligned} \tag{4.3}$$

Deviance change	=	-622.9
Residual deviance	=	1297.2
d.f.	=	1620

Figures in brackets are t-statistics

where

LINC	=	Natural logarithm of respondents household income (continuous variable)
BOAT	=	1 if respondent does participate in some boating activity (=0 otherwise)
RELAX	=	1 if respondent visits area to relax/enjoy scenery often (=0 otherwise)
ENV	=	1 if respondent is a member of an environmental group (=0 otherwise)

other variables as previously defined

Although not significant at $\alpha = 5\%$, the variable LINC is included in equation (4.3) to underline the finding that, although complying with expectations, the respondents income plays a very weak (statistically insignificant) part in determining response to dichotomous choice WTP questions. While economic theory would lead us to expect the 'price' variable (LBID) to be the most significant, its degree of dominance over other variables, particularly income, is of interest. We comment on these findings subsequently.

In calculating mean WTP from a DC experiment an important issue is the choice of truncation option prior to integration of the CPD. This issue is analysed in detail in Bateman et al. (1993, 1995a) and Langford and Bateman (1993). For reasons given in these papers we

[17]As an ancillary test of this result, individual models were fitted for the data within each bid level ($214 \leq n \leq 227$ for each level). All of the eight models produced were exceptionally weak. This is inevitable for the lower bid levels where very few respondents registered refusals i.e. very little variation. However even the best of these models (for the £50 bid level) only recorded a change in deviance of -24.65 with residual deviance being 223.73. These results confirm the key role of the bid level in determining responses.

[18]Alternative models are considered in Bateman et al. (1993).

follow Hanemann (1989) in preferring a non-negative but positive untruncated approach. Applying this approach to our simple bid function (4.2) gives a mean WTP estimate of £143[19] while for our 'best fit' model the mean is very similar at £140 underlining the relative unimportance of the non-BID variables.

iii. Comparing OE and DC results

Do our findings from the OE and DC experiments conform to economic theory or is there evidence of the psychological biases discussed in chapter 2? The most common assessment of elicitation effects has been through comparison of means and our study confirms the general finding of DC mean exceeding that from the OE experiment (Sellar et al., 1985; Walsh et al., 1989; Kriström, 1990; 1993). However, this result above gives little indication regarding the validity of either approach. Indeed, as Kriström (1993) points out, even if means were the same this need not imply similarity of distribution.

Figure 4.2 presents both DC and OE response distributions in the form of survival functions for those WTP at least some amount (i.e. excluding, for both formats, all those respondents who refused to pay anything at all). Here the proportion of DC respondents giving positive responses at each bid level is compared with the proportion of OE respondents stating WTP sums equivalent or greater than that bid level. In the absence of any elicitation effects these proportions should roughly coincide across the bid vector. However, we can see that the DC format apparently generates a response distribution which is shifted outwards compared to that of the OE approach[20].

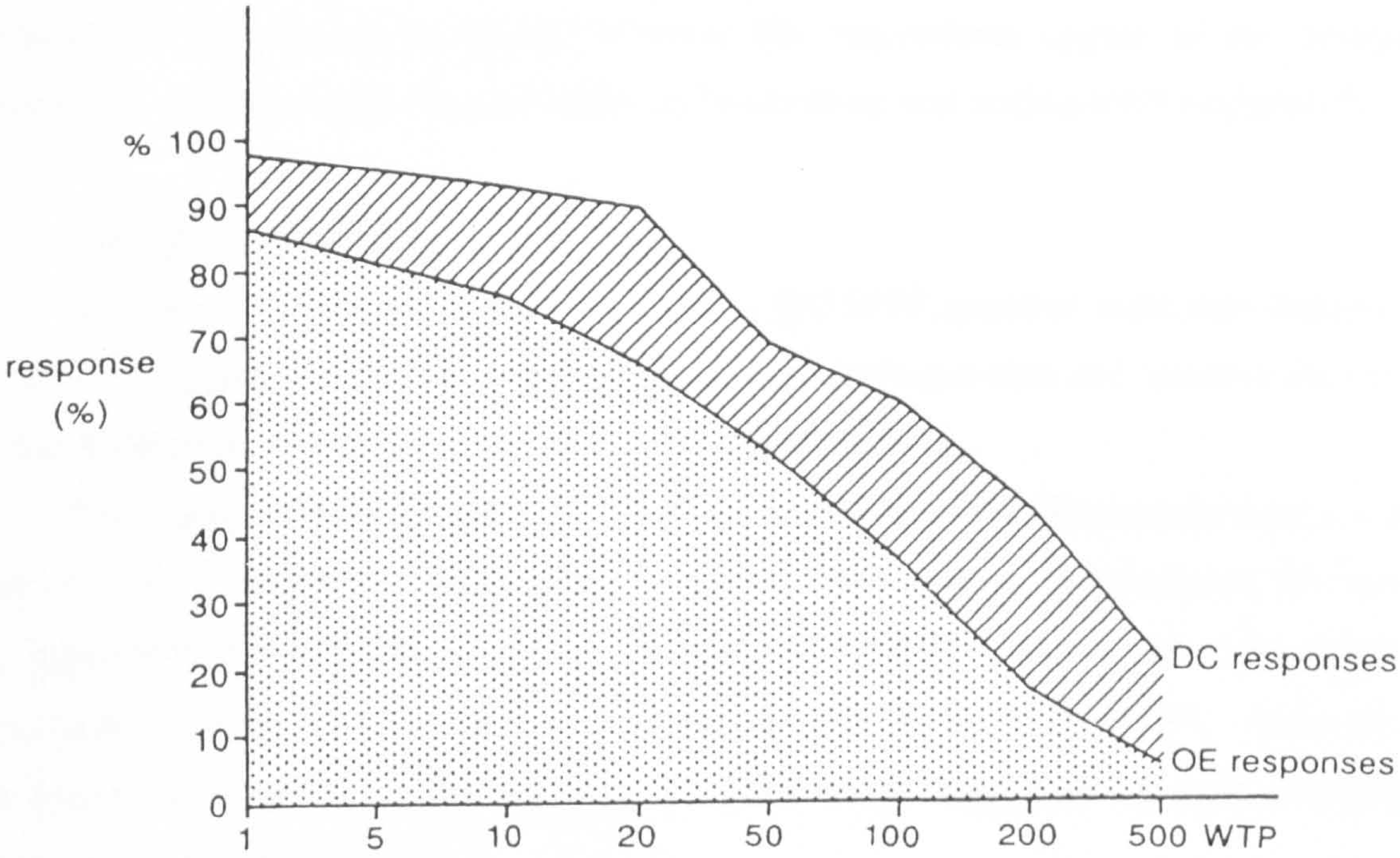
Figure 4.2 suggests that it is more likely that a respondent will agree to pay a particular amount X when presented with that amount as a DC bid level, rather than via an OE experiment. This discrepancy can be viewed from either an economic or psychological perspective. Economic theory suggests that the OE format provides no incentive for overstatement (Hoehn and Randall, 1987) and may be subject to free-riding or expected cost effects both of which will give an incentive to understate WTP. Furthermore, given the

[19]95% CI calculated as per the geometric method of Langford and Bateman (1993) is £75-£261. Calculation of a 95% CI for the more complex 'best fit' model (4.3) is difficult and not attempted as results would obviously be very similar.

[20]It is interesting to note that this figure is very similar to that reported by Kriström (1993) in his study of preservation values for Swedish forests. This similarity would be even greater if we were to extend our WTP axis to include OE strategic overbidders/yea-sayers and their expected DC counterparts had even higher DC bid levels been used.

necessary assumptions (discussed in chapter 2), truth-telling is the optimal strategy in a DC format (ibid). The observed discrepancy between OE and DC results is therefore not inconsistent with economic theory. However, such results can also be explained in terms of certain of the 'psychological' biases discussed in chapter 2. Here, commentators have seen OE/DC divergence as evidence of some sort of anchoring effect in the DC responses (Kahneman and Tversky, 1982; Roberts et al., 1985; Kahneman, 1986; Harris et al., 1989) and we can use this as a generic term for the overall effect of the various potential DC biases identified.

Figure 4.2: Survival functions for OE and DC responses



Testing for such anchoring is problematic. Kriström (1993) discounts comparisons based upon means because of their implicit assumptions regarding distributional form. He suggests the use of non-parametric tests based upon the distance between the OE and DC survival functions. However, there are various complications associated with the simultaneous application of such an approach to discrete and continuous data. Kriström therefore uses a simple chi-square test to show that the OE and DC responses do not come from the same distribution. This is supplemented by a somewhat unusual test of an anchoring hypothesis in which responses from the OE sample are compared with supplementary OE responses given by the DC sample. Although, as Kriström states, the distance test used is known to have low power,[21] it is interesting to note that the computed statistic actually rejects the anchoring hypothesis ($\alpha = 5\%$).

However, comparative analysis can be used to illustrate the strength of the apparent cognitive difference between responses to OE and DC questions. In order to underline this difference it was decided to treat all the OE responses as if they had come from DC questions, i.e. an OE WTP bid of £10 was taken as a 'yes' response to bid levels £1, £5 and £10 and a 'no' response to all others. Here the (optimal) log-logistic model gave a very much poorer fit to the data (residual deviance of 227.72 with 6 degrees of freedom) than it did for the genuine DC data (residual deviance of 6.24). This indicates that the format used in DC questioning places respondents within a fixed framework of evaluating their WTP, very well described by the log-logistic model, whereas OE respondents appear to be undergoing significantly different cognitive processes in formulating and stating their responses[22].

iv The IB experiment

All respondents initially presented with a DC WTP question were then entered into the IB bidding game. Discussion of the payment principle question and 'reasons for refusal' for the IB sample are therefore as for the DC experiment.

The open-ended WTP question presented at the end of the IB procedure gave a mean WTP of £74.91 (95% CI = £69.27; £80.55). However, as in the OE experiment, this amount was highly responsive to the truncation of higher WTP bids[23]. Omission of the upper 5% of responses, for example, resulted in a 30% decline in the mean to £52.41. As in the OE experiment then, the possibility that certain respondents engage in strategic overbidding cannot be ruled out.

As the final WTP bid in the iterative bidding game was given in response to an OE question, the dependent variable in any bid curve estimation will be continuous but truncated at zero. Bid function analysis quickly revealed a strong positive association between the DC bid level presented to respondents (which constituted the starting point of the IB game) and the final WTP amount stated by respondents at the end of the IB process. This relationship

[21] The Kolomogorov-Smirnoff test; see Kanji (1993).
[22] Another approach might be to compare common covariates in the OE and DC bid functions.
[23] Full results in Bateman et al., 1993.

was strongest when both the final WTP response and the initial bid level were expressed as natural logarithms. The optimal model is given as equation (4.4).

$$\begin{aligned} \text{LWTP(IB)} = {} & \underset{(22.18)}{2.104} + \underset{(19.79)}{0.3733}\ \text{LBID} + \underset{(1.86)}{0.000005}\ \text{INC} \\ & + \underset{(3.67)}{0.1758}\ \text{BOAT} + \underset{(4.70)}{0.1720}\ \text{ENV} - \underset{(-2.89)}{0.1222}\ \text{FIRST} \end{aligned} \tag{4.4}$$

R^2 = 21.86%
Total df = 1634

where: LWTP(IB) = natural log of respondents final WTP statement in the IB game.
LBID = natural log of the bid amount offered to respondents
INC = respondents household income (continuous variable)
FIRST = 1 if respondent is on his/her first visit to the area (=0 otherwise)
Other variables as previously defined.

Signs on the explanatory variables of equation (4.4) are as expected. The variable INC is included for interest although it is only significant at the 90% confidence level. Interestingly when tested, the variable LINC was found to be significantly weaker. As expected, ignoring the constant, by far the most powerful explanatory variable was the (log) bid level first presented to respondents. This appears to have strongly anchored respondents into a corresponding range of final WTP bids, i.e. a classic starting point effect.

In their theoretical analysis, Hoehn and Randall (1987; p.237) appear to imply that DC and IB approaches, when started from identical bid levels, should yield similar mean results. Clearly this has not occurred in this case. Our IB format can be viewed as an amalgam of the DC and OE approaches and as such it is not surprising that we see evidence of several of the characteristics of those formats reflected in IB responses. The power of the initial bid level, so dominant in the DC bid functions, is clearly apparent. However, the IB approach now allows for OE 'understatement' traits such as free-riding or expected-cost strategies to emerge as reflected in the reduced estimate of mean WTP.

v. The MLM experiment

An interesting characteristic of the WTP data was identified by comparing responses as they developed across the first, second and third dichotomous bounds. Here it was noticed that, *at all bid levels*, respondents exhibited a certain unwillingness to accept a doubling of a previously accepted amount. This trend was, to varying extents, apparent whether that previous amount was £10 or £500, and continued to appear (and intensify) at successive bounds. At the second (or third) bound respondents appear to view their previous accepted bid as more or less representing their total WTP and therefore resist the further doubling of this amount. This means that, at a given bid level, we are likely to have a lower proportion of recorded refusals at the first bound than at the second (because those doubling up from an initial lower bid level may refuse to pay this amount). This will mean that the discrete variable estimate of mean WTP will fall between bounds, a result which accords with the findings of Hanemann et al. (1991).

The bid function for the MLM experiment was estimated by Ian Langford and is therefore not reported upon here (full details in Langford, Bateman and Langford, 1994, 1996). However, this model confirms our DC finding that, in such experiments, the bid level presented to respondents is by far the strongest influence upon response. Our initial observation of a downward bias across DC bid levels is also confirmed in this analysis. Possible reasons for such a bias are interesting. Carson et al. (1994) suggest two routes by which such an effect may operate:

A. Respondents who agree to the initial DC amount and would, a-priori, have paid the (higher) 2DC amount may still refuse the latter if they feel that the government would waste the extra money.

B. Respondents who refuse the DC bid but would, a-priori, have paid the (lower) 2DC amount may still refuse the latter if they equate this lower amount with a reduction in either the quality of the good or its probability of provision.

Both these response patterns arguably accord with economic theory regarding expectation formed by the initial DC amount. However, we argue that type A reactions may also be augmented by psychological influences regarding preferences for the initial status quo (as per Knetsch, 1993) and a consequent feeling by respondents that the initial DC response represented an agreed price which they then become attached to and unwilling to increase. These effects will intensify between the 2DC and 3DC question and are reflected in the overall ML estimate of mean WTP which, for the 3DC response, is about £82, i.e. considerably lower than that for our analysis of responses to the initial DC bid level.

vi. Summary and conclusions

Table 4.3 summarises mean WTP results from our analysis of elicitation effects. While there are some similarities across elicitation methods (i.e. optimal bid functions contain a number of common explanatory variables and the confidence intervals of the mean WTP estimates also overlap), there are more dominant differences. The possibility of conflicting effects such as free-riding and strategic overbidding, as well as considerable uncertainty (high variability) within OE responses seems likely. However, many, if not all, of these characteristics can be accounted for within economic theory.

Table 4.3: Mean WTP results from four elicitation methods

Elicitation Method	Mean WTP (£)	95% Confidence Level	
		Lower (£)	Upper (£)
DC	143.18	75.00	261.00
IB	74.91	69.27	80.55
MLM (3DC)	81.65	44.32	118.97
OE	67.19	59.53	74.86

The disparity between OE and DC results might also be explained by economic theory. However, psychological arguments may also be valid here. The large influence of the bid level within the DC bid function can be interpreted either as an expected economic price effect, or as an anchoring bias. Because of the number of potential exacerbating, conflicting and confounding effects discussed with respect to both formats, we have doubts about the usefulness of simple comparisons between OE and DC results. Rather we choose to emphasise the results of the test which treated OE data as if it were derived from DC questioning. This indicates that there is a highly significant cognitive response difference depending on which question format is being used. These differences in interpretation appear to indicate that the mental processes initiated by these questions include certain quite separate elements, probably both economic and psychological. Such conclusions seem to be reinforced by the findings of our MLM analysis which echoes our DC findings but introduces further economic/psychological influences upon respondents.

The IB approach can be seen as a hybrid of both the DC and OE formats and as such demonstrates a mix of the effects associated with both. The dominance of the bid level, so characteristic of the DC approach, is clearly evident as a classic starting point bias (Roberts et al., 1985). It appears that, once the initial (DC) response is elicited (possibly raising stated WTP), the ensuing respondent control may engender OE-type 'understatement' strategies.

In conclusion, our elicitation effect study has raised important issues regarding the optimal strategy for our remaining research. The bulk of economic theory appears to suggest that DC approaches will come nearest to eliciting 'true' WTP[24] while OE methods will lead to some understatement of such amounts. Conversely, psychological theory suggests that, while OE responses may suffer from both under and overstatement in separate respondents, DC methods will generally exhibit overstatement as a result of the group of influences we have labelled as anchoring. Furthermore, we have shown that these arguments and others applying in varying degrees to both the IB and MLM approaches.

We are therefore forced to adopt a pragmatic solution to this quandary[25]. The US NOAA panel guidelines on CV (Arrow et al., 1993) clearly state that a conservative design more likely to underestimate WTP is to be preferred to one likely to overestimate WTP. Such guidance seems reflected on this side of the Atlantic by the interpretation of UK environmental evaluations by H.M. Treasury[26]. Consequently we have adopted OE elicitation techniques for the remainder of our research on the grounds that these are likely on-balance to give lower-bound estimates on WTP. However, in interpreting final results, the possibility that true WTP may exceed such amounts should not be overlooked.

4.3 WOODLAND RESEARCH

Three separate woodland recreation evaluation studies were conducted which we shall

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[24]Sugden (forthcoming) fundamentally questions whether or not the concept of 'true' preferences is defensible arguing that while CV researchers see the main problem as the minimisation of bias, others argue that preferences alter according to the question being asked (rather than just how it is asked) and cannot therefore be statically 'true' in the sense implied by CV studies.

[25]The alternative - to abandon our valuation exercise - being rejected on the grounds that non-economic approaches have failed to adequately assess the recreation value of environmental goods. For a contrary view see Adams (1994) who argues that monetary evaluation methods cannot capture the diversity of values generated by environmental public goods.

[26]Conversation with numerous senior colleagues (who would doubtless prefer to remain anonymous) at various UK institutions confirm the preference of H.M. Treasury for lower-bound assumptions in such studies. The nearest thing to written confirmation of this is given in Whiteman (1994).

refer to as: Thetford 1 (carried out in 1990); Wantage (1991); and Thetford 2 (1993). The first two of these were conducted prior to the Norfolk Broads study discussed previously. Fortunately the approach of the Thetford 1 and Wantage studies does not contravene our later findings. However, the experience gained during the Norfolk Broads and subsequent evaluation studies means that our later Thetford 2 study is designed to a much higher specification than our earlier woodland research.

In the remainder of this section we present summaries of our applied work. Where relevant full details are given in appendix 2.

4.3.1 THE THETFORD 1 CV/TC STUDY

The Thetford 1 study was conducted in the summer of 1990 and consisted of a series of face-to-face interviews[27] with both users and non-users regarding the recreational value of Thetford Forest in Norfolk. The overall sample was sub-divided to permit a number of differing CV analyses in addition to an ITC study of users. The structure of sub-sample analyses was as follows:

A. CV studies:

1. Users (forest) surveys
    - i. WTP via annual payment: tax vehicle; OE elicitation method
    - ii. WTP via per visit payment: entrance fee vehicle; elicited using low range payment card
    - iii. WTP via per visit payment: entrance fee vehicle; elicited using high range payment card
2. Non-users (Norwich city) surveys
    - i. WTP via annual payment: tax vehicle; OE elicitation method
    - ii. WTP via annual payment: poll-tax[28] vehicle; with OE elicitation method
    - iii. WTP via per visit payment: entrance fee vehicle; elicited using low range payment card
    - iv. WTP via per visit payment: entrance fee vehicle; elicited using high range payment card

[27]The author is grateful to Joanne Wall (UEA student) who conducted interviews for this exercise.
[28]More properly termed the 'Community Charge'.

B. ITC study

Questionnaires for the on-site (CV/TC) and Norwich (CV) studies are reproduced in appendix 2.

4.3.1.1 Thetford 1: CV studies

All CV samples were collected using face-to-face interviewing of randomly selected respondents. In all the per annum (but not per visit) CV evaluation studies it was decided, prior to any WTP question, to inform respondents of the current average level of annual per household payments to support the Forestry Commission which was estimated at approximately £2.60 pa[29]. This approach followed contemporary practice in UK CV studies particularly as pioneered in the work of Turner and Brooke (1988), a study which had recently been approved (as part of a wider CBA[30]) by H.M. Treasury.

A number of socioeconomic variables were collected in all surveys. In the case of the on-site interviews with forest users these included: home address; sex; age; employment; whether the interviewee was a pensioner; income; precise interview location; preference for natural or urban recreation; history and frequency of visits to the specific site and forest entirety; time spent on site; and use value WTP[31]. Similar variables were elicited from the non-user samples with the addition of questions regarding respondents knowledge of the forest and integral visitor sites.

In all studies WTP responses were investigated by regression analysis of underlying bid functions. Here a variety of analyses concerning the specification and functional form of bid curves was undertaken. However, for reasons of brevity only best fitting models are reported. Results were then compared across studies to see if differences could be explained.

i. <u>The per annum payment studies: results</u>

In this section we report results from those studies in which respondents were presented with evaluation questions asking for their WTP per annum for the recreational

[29]Based upon Forestry Commission (1985).

[30]For a review of the overall project (including the CV study) see Turner, Bateman and Brooke (1992).

[31]A use + option value WTP was also elicited, but following our criticisms of chapter 3, this is not considered further.

facilities provided by Thetford Forest. As noted, all respondents to these studies were informed of the present level of mean annual per household tax contributions in respect of Forestry Commission grant-in-aid (£2.60 pa).

A. On-site survey: WTP direct tax per annum

Responses were elicited using an OE WTP question and a general income tax payment vehicle. A useable sample of 46 interviews was collected[32] of which 40 (87%) were WTP at least some amount for the recreational facilities provided at Thetford Forest. WTP bids generally ranged from £0.10 to £10.00 per annum with three notable exceptions; two bids of £50.00 and one of £52.00. This gave an all sample mean WTP of £5.14[33] but a 5% trimmed mean of £3.20. Univariate WTP statistics are presented subsequently in comparison with those from the other per-annum studies. Estimation of a bid function for such a skewed distribution was problematic. However, a log (dependent) functional form satisfied an n-scores normal distribution test (MINITAB, 1991) and the best fitting model is given in equation 4.5[34].

$$\text{lnWTPftx} = \underset{(5.28)}{1.146} - \underset{(-2.31)}{0.652}\ \text{STAY210M} + \underset{(1.71)}{0.490}\ \text{DAYS12} \qquad (4.5)$$

$R^2 = 20.1\%$ $\qquad R^2(\text{adj}) = 16.5\%$ $\qquad n = 46$

where:

lnWTPftx	=	natural log of WTP response of forest users to per annum (tax vehicle) question
STAY120M	=	1 if respondents average length of visit was at least 120 minutes; = 0 otherwise
DAYS12	=	1 if respondent visited forest at least 12 times per annum; = 0 otherwise

Figures in brackets are t-statistics

Equation 4.5 is not particularly strong and reflects, we believe, the rather crude nature

[32]A further 4 interviews were incomplete.

[33]Zero bids were not excluded.

[34]We accept criticisms that, strictly speaking, OLS techniques should not be used in cases of discrete observations with some zeros. However the distribution was not particularly blocky and little improvement would be gained by using highly technical solutions upon such data.

of our early evaluation work. Nevertheless it does satisfy the overall fit requirements of some CV commentators (see chapter 2) and the individual relationships described seem plausible. It appears that regular/short stay visitors have higher annual WTP than do irregular/long stay visitors[35]. The former group seem straightforward (WTP rising with use). Further analysis of the latter occasional visit/long-stay group revealed that these individuals had generally travelled relatively long distances to the forest. Accordingly they were more likely to have a wider range of substitute recreational options for such visits than do the 'regular visitor' group and therefore a lower annual WTP is again logical.

B. Remote survey: WTP direct tax per annum

Although this survey was conducted in the centre of Norwich, some 25 miles remote of Thetford Forest, it would be misleading to think of this as a survey of pure non-use value as, of the sample of 53 respondents, 41 (77%) knew of the forest, while 25 (53%) had visited it. 49 fully completed questionnaires were collected of which 41 (84%) were WTP at least some amount for the recreational facilities provided at the forest. WTP bids generally ranged from £0.10 to £10 with three exceptions: two bids of £20 and one of £52 (coincidentally the same as the highest on-site bid). This gave an all sample mean WTP of £3.51 with a 5% trimmed mean of £2.22 (univariate WTP statistics are detailed subsequently). N-scores testing confirmed the bid function to be log (dependent) normal and the best fitting model is given in equation 4.6.

$$\ln WTPntx = \underset{(-0.93)}{-2.33} + \underset{(2.04)}{2.07}\ HOME + \underset{(2.04)}{0.260}\ VISARB \tag{4.6}$$

$R^2 = 14.7\%$ $R^2(adj) = 11.0\%$ $n = 49$

where:

lnWTPntx = natural log of WTP response of Norwich subsample to per annum (tax vehicle) question
HOME = 1 if respondents home address is in Norfolk or Suffolk; 0 = otherwise
VISARB = 1 if respondent had visited Thetford Forest (Arboretum site).
Figures in brackets are t-statistics.

[35] Tests of potential collinearity between the explanatory variables (correlation coefficients and impact upon coefficients of omitting one variable in turn) suggest this is not a significant problem.

Equation 4.6 is arguably even weaker than that for the forest users (4.5), a finding which is unsurprising given the generally lower level of site knowledge of the Norwich subsample. However, the relationship with individual explanatory variables is logical indicating that those who live closer to the forest as well as those who actually visit it have a higher annual WTP[36].

C. Remote survey: WTP poll tax per annum

This subsample was collected in a manner identical to that described at *B* above except that the payment vehicle was altered to the Community Charge or 'poll' tax. This was a local taxation system which had recently been imposed upon local councils by the government of the day. The tax was the subject of extreme controversy at the time of our survey. While normally any CV survey would attempt to avoid a controversial payment vehicle, in a comparative test such as ours, other factors could be held relatively stable and the strength of reaction to the vehicle alone, assessed.

It was quite clear from responses that interviewees reacted very strongly to the use of the poll tax vehicle. Refusals to pay increased dramatically such that only 23 respondents (49% of the total subsample of 47) were willing to pay anything at all (compared to 84% of the Norwich direct tax respondents). However, the distribution of non-zero bids was much less concentrated upon low amounts than in the other per annum experiments with far more relatively high bids being recorded. This resulted in an all-sample mean of £7.09 and a 5% trimmed mean of £5.19. Statistical analysis revealed that both the decision to bid and the magnitude of bid were much more strongly correlated with respondents income than any explanatory variable had been in the other experiments. No other variable proved significant in explaining WTP responses under the poll tax vehicle, and the best fitting bid function is given as equation 4.7[37].

$$\ln WTPnpoll = \underset{(-0.37)}{-0.129} + \underset{(3.72)}{0.000098}\ INCOME \qquad (4.7)$$

$R^2 = 23.6\%$ $R^2(adj)\ 21.9\%$ $n = 47$

[36] Tests for multicollinearity showed no problem here.

[37] As before an n-scores test confirmed the suitability of the log-dependent functional form.

where:

lnWTPnpoll	=	natural log of WTP response of Norwich subsample to per annum (poll tax vehicle) question
INCOME	=	respondents household annual income (£)

Figures in brackets are t-statistics.

It appears from equation 4.7 that high income individuals react positively to the poll-tax vehicle by increasing their stated WTP while the reverse is true of low income respondents, many of whom state a zero WTP under the poll tax vehicle. If we characterise supporters of the Government and its policies as typically having above average incomes then this result can be interpreted as reflecting political preferences.

D. Comparison across the per annum studies

Analysis of responses across our three per annum studies reveals some interesting findings. Our first consideration was to investigate the socioeconomic characteristics of respondents across subsamples to check for confounding factors etc. Summary statistics for this analysis are given in table 4.4.

Comparison of the two Norwich subsamples shows a reassuring similarity between those facing the tax and poll tax questions. The only factor which is significantly different between the two groups concerns the 'home' variable as all those facing the poll tax vehicle came from the Norfolk/Suffolk area. This is somewhat offset by the slightly higher income in the direct tax sample, although this latter difference is statistically insignificant.

While the two Norwich subsamples seem very similar the Thetford Forest sample is very different and appears likely to come from a separate underlying population. The 'home', 'income' and (obviously) 'visForPa' variables appear to be quite dissimilar (although 95% confidence intervals do overlap to at least some extent). While the visits data comes as no surprise, differences in the income variable suggest that visitors to Thetford Forest enjoy a generally higher ability to pay than do the population represented by our Norwich subsamples. This factor, combined with the higher use rate of on-site interviewees supports the observed higher mean WTP (and WTP distribution characteristics) of this group than those faced with the same (direct tax) question in the Norwich survey. Table 4.5 gives univariate WTP statistics for all three subsamples faced with per annum WTP questions.

Table 4.4: Socioeconomic characteristics of the Thetford 1 per annum WTP subsamples

variable	n	mean	st. dev	se mean	95% CI	
					lower limit	upper limit
Thetford survey: WTP direct tax						
sex	50	0.62	0.49	0.07	0.48	0.76
age	50	1.94	0.74	0.1	1.73	2.15
home	50	0.76	0.43	0.06	0.64	0.88
income	50	15800	9793	1385	13016	18584
knowFor	n/a	n/a	n/a	n/a	n/a	n/a
visFor10	n/a	n/a	n/a	n/a	n/a	n/a
visForPa	50	5.98	10.25	1.45	3.07	8.89
Norwich survey: WTP direct tax						
sex	53	0.59	0.50	0.07	0.45	0.72
age	53	1.68	0.73	0.10	1.48	1.88
home	53	0.917	0.30	0.04	0.82	0.99
income	53	12679	9243	1270	10131	15228
knowFor	53	0.77	0.42	0.06	0.66	0.89
visFor10	53	0.47	0.50	0.07	0.33	0.61
visForPa	53	1.89	4.47	0.61	0.65	3.12
Norwich survey: WTP poll tax						
sex	50	0.58	0.50	0.070	0.44	0.72
age	50	1.72	0.78	0.11	1.5	1.94
home	50	1.00	0.00	0.00	1.00	1.00
income	50	11175	6524	923	9320	13030
knowFor	50	0.78	0.42	0.06	0.66	0.90
visFor10	50	0.50	0.51	0.07	0.36	0.64
visForPa	50	2.21	5.53	0.78	0.64	3.78

where:

sex	= 1 if male; 0 if female
age	= category variable (1 = young; 2 = middle aged; 3 = old)
home	= 1 if home is in Norfolk or Suffolk; 0 otherwise
income	= household annual income (£)
knowFor	= 1 if respondent knows of Thetford Forest; 0 otherwise
visFor10	= 1 if respondent has visited Thetford Forest; 0 otherwise
visForPa	= average number of visits to Thetford Forest per annum

Notes: 1. All values identical (all 'home' respondents)
n/a = question not applicable to on-site survey

Table 4.5 also shows the dramatic impact of changing payment vehicles. With the common direct tax vehicle, the higher use rate and ability to pay of Thetford visitors (FTAX) leads to a mean WTP in excess of that for Norwich interviewees (NTAX). However, switching to the controversial poll-tax vehicle (NPOLL) reverses this situation. Figure 4.3

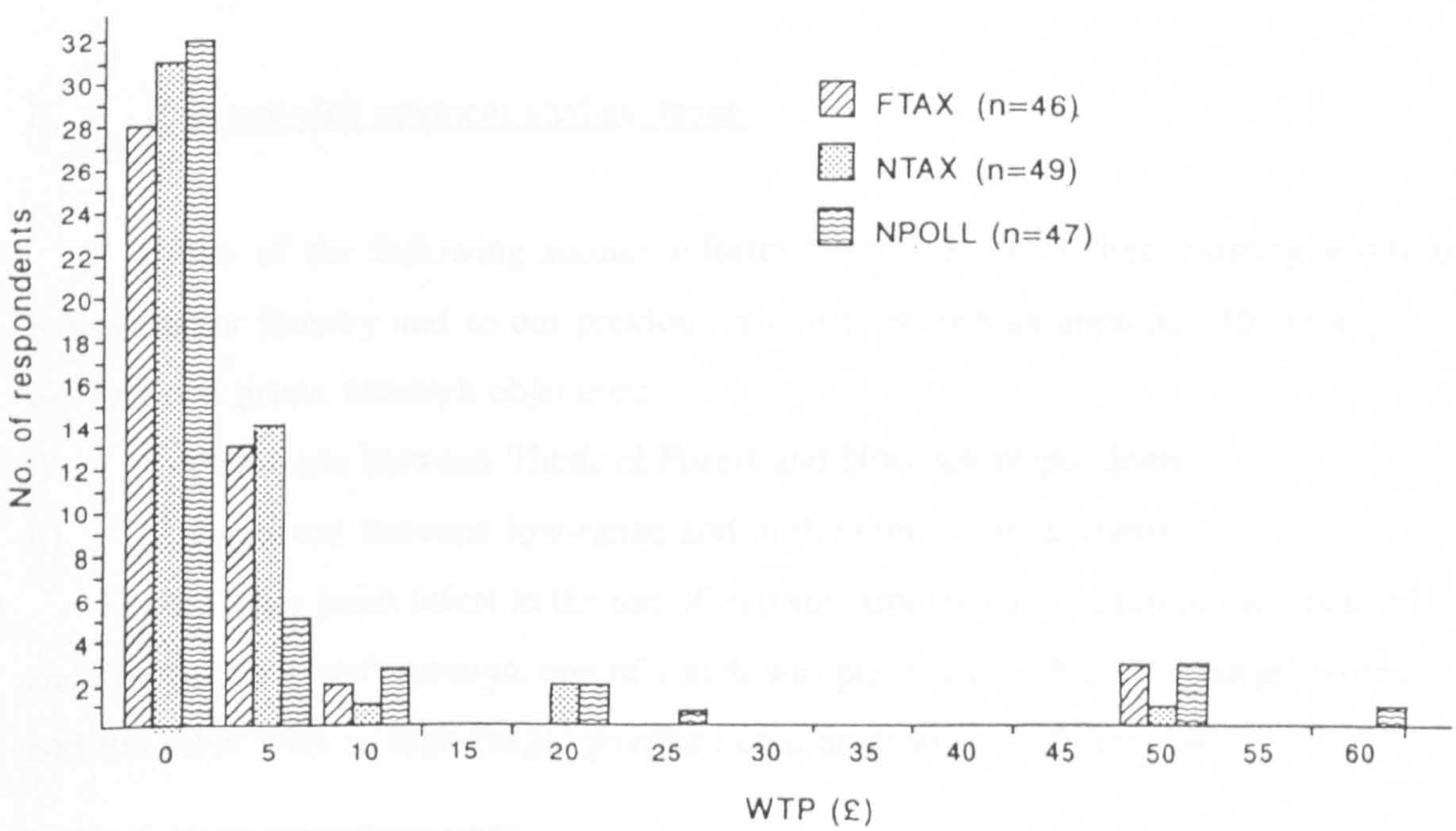
clarifies what has happened by plotting out the WTP distributions derived from each subsample. The switch to the poll tax vehicle increases the number of zero bids but, more importantly (with respect to impact upon mean WTP), also raises the number and magnitude of relatively large bids. It appears that in all three cases there are small groups of respondents prepared to pay proportionately very high amounts but that the poll tax vehicle considerably inflates this trend.

Table 4.5 Univariate WTP statistics for per annum subsamples

Group	n	mean (£ pa)	median (£ pa)	tr. mean (£ pa)	st. dev (£ pa)	se mean (£ pa)	95% CI (£ pa)	
							lower	upper
FTAX	46	5.14	2.00	3.20	12.35	1.82	1.48	8.81
NTAX	49	3.51	0.70	2.22	8.26	1.18	1.13	5.88
NPOLL	47	7.09	0.00	5.19	15.02	2.19	2.68	11.50

Notes: FTAX = Thetford Forest subsample asked WTP pa via direct tax
NTAX = Norwich subsample asked WTP pa via direct tax
NPOLL = Norwich subsample asked WTP pa via poll tax
Number of incomplete questionnaires (refused to give WTP bid) as follows: FTAX = 4; NTAX = 0; NPOLL = 3.
Minimum bid is zero for all subsamples (not excluded from calculation of mean).
tr. mean = 5% trimmed mean

Figure 4.3 Distribution of WTP responses across the per annum evaluation subgroups



Notes: FTAX = Forest survey, WTP tax pa
NTAX = Norwich survey, WTP tax pa
NPOLL = Norwich survey, WTP poll tax pa

Returning to table 4.5, another important finding is that WTP confidence intervals for the FTAX and NTAX groups indicate that mean WTP is not significantly dissimilar from the amount which respondents were informed of as being their current annual payments for this good. Comparison of the FTAX results with those for our subsequent Thetford 2 study (which included a very similar subsample) show a marked difference in WTP distribution[38]. We conclude that many respondents did use this information regarding existing payments as an anchoring point on which to base their WTP response. We feel that this conclusion also applies to the NPOLL subsample and that the fact that the £2.60 information point falls outside the 95% CI for this group merely underlines the dramatic strength of the payment vehicle effect exhibited by this group of two very distinct halves (most likely reflecting the political persuasion of individual respondents which in turn is proxied by the income variable).

In conclusion, the Thetford 1 per annum experiments yield some interesting findings particularly regarding payment vehicle and information effects. Ignoring such effects would lead to considerable bias in WTP results. The study was useful in that it gave us reasons to reject both the poll tax vehicle and the use of present-payment information in our subsequent evaluation exercises. However, for the same reasons, we are dubious regarding the validity of the evaluation estimates produced from this particular exercise and to not use them in our later benefit transfer work.

ii. <u>The per-visit payment studies: results</u>

None of the following studies informed respondents of their existing levels of tax payments for forestry and so our previous criticism of such an approach do not apply. Here we had two prime research objectives:

i) Comparison between Thetford Forest and Norwich respondents

ii) Comparison between low-range and high-range payment cards.

The latter point refers to the use of two subsamples within each of the Thetford Forest and Norwich per-visit surveys, one of which was presented with a 'low-range' payment card and the other with a 'high-range' payment card as detailed in figure 4.4.

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[38]Differences in mean WTP between these studies and other per annum analyses (not informing respondents of current payment levels) are most vividly illustrated in our review of per annum evaluations in chapter 3.

Figure 4.4 Per-visit studies: payment card ranges

low-range payment card (£):

0	0.50	1.00	1.50	2.00	2.50	3.00	Other (specify)

high-range payment card (£:)

2.00	2.50	3.00	3.50	4.00	4.50	5.00	Other (specify)

A further consideration was to compare per visit with per annum measures. However, given our reservations regarding the absolute value of per annum estimates in the light of apparent anchoring from information regarding the present level of tax payments, such a comparison was of dubious validity. Accordingly both per visit and per annum measures were used in our subsequent study at Wantage where respondents were not informed of present tax payment levels.

A. *On-site surveys: WTP entrance fees*

Comparison of the low-range and high-range payment card subsamples reveals interesting differences and similarities. In both cases WTP was negatively correlated with the number of visits but positively correlated with the length of time spent on-site during visits. Both results are highly logical, indicating that those who take frequent but short visits are averse to the entrance fee vehicle as this will incur a high overall cost given their visiting pattern. Conversely those who make infrequent but long duration visits would see the entrance fee as relatively good value for money, and consequently stated relatively higher WTP sums. The inverse correlation between trip frequency and visit duration (essential for such a line of reasoning) was clearly evident in both subsamples. However, the presence of such multicollinearity meant that these two variables could not be entered into the same bid function. Table 4.6 lists zero-order Pearson correlation coefficients for these relationships. It is interesting to note that, in every case, the relevant coefficient for the low-range subsample is weaker than that for its high-range equivalent. This suggests that the low-range payment card has restricted the range of bids stated by respondents even though, in theory, the payment card allowed for any bid.

Table 4.6 Correlation coefficients: on-site WTP fees and relevant explanatory variables

Variables	low-range payment card		high-range payment card	
	lnWTPffl	lnVISITS	lnWTPffh	lnVISITS
lnVISITS	-0.128		-0.704	
LONG	0.254	-0.166	0.404	-0.335

where: lnWTPffl = natural log WTP entrance fees forestry subsample presented with low-range payment card
lnWTPffh = natural log WTP entrance fees forestry subsample presented with high-range payment card
lnVISITS = natural log of number of visits per annum of respondents in respective subsample
LONG = 1 if respondents average time on-site was at least 150 minutes per visit; = 0 otherwise

Given that, due to multicollinearity, the visit rate (lnVISITS) and visit duration (LONG) variables could not simultaneously be included in any bid function[39], specifications were data determined. In the event the low-range subsample is specified in terms of the LONG variable while the high-range subsample contains the lnVISITS variable. This derives from the somewhat larger proportion of long-duration visitors in the low-range (54%) than high-range (46%) subsample. Equation 4.8 gives the best-fitting model of the low-range payment card responses:

$$\underset{}{\text{lnWTPffl}} = \underset{(10.52)}{0.706} + \underset{(2.05)}{0.179}\ \text{LONG} \underset{(-3.37)}{-0.381}\ \text{PENSION} \qquad (4.8)$$

$R^2 = 24.6\%$ $R^2(\text{adj}) = 21.4\%$ n = 50

where:

PENSION = 1 if respondent of pensionable age; 0 = otherwise

Other variables defined in notes table 4.6. Values in brackets are t-statistics.

[39]The correlation matrix (table 4.6) shows that this is not a clear cut decision particular for the low-range payment card responses. Omitted variable tests did not add much clarity to this decision.

The relationships of equation 4.8 are as expected with the PENSION variable possibly acting as a proxy for ability to pay although, interestingly, this was stronger than an income variable. Equation 4.9 gives the best fitting model of the high-range payment card responses.

$$\ln WTPffl = \underset{(15.28)}{1.26} - \underset{(-6.87)}{0.237} \ln VISIT \quad (4.9)$$

$R^2 = 49.6\%$ $\quad$ $R^2(adj) = 48.5\%$ $\quad$ $n = 50$

Variables as defined in notes to table 4.6. Values in brackets are t-statistics.

The strength of equation 4.9 is, by CV standards, quite remarkable. However, its simplicity is a little worrying, suggesting that many standard economic factors (such as income) have little relevance to these responses (although further analysis showed all relationships to be correctly signed if of low significance).

We would suggest that the apparent power of both equations 4.8 and 4.9 may have been inflated by two related factors:

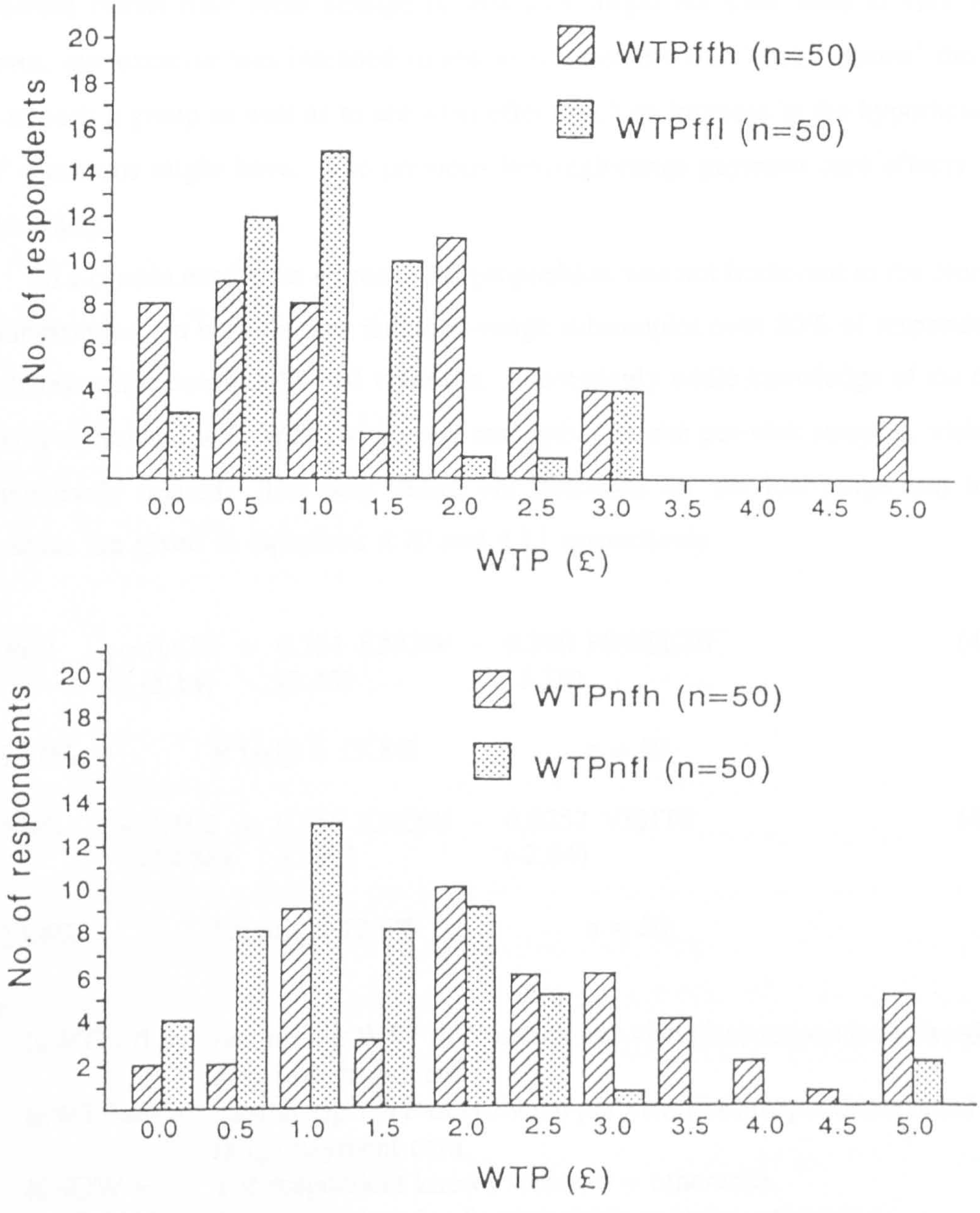
i) Respondents concepts of a socially reasonable amount to pay per visit (as per our discussion of the concept of a 'social norm' value in chapter 2).

ii) The restrictions upon bids as perceived by respondents facing the payment card vehicles.

Evidence for such conclusions is given by the strength of the constant in both bid functions. While this itself questions the economic validity of such responses, it is encouraging to note that, in the high-range experiment where the perceived restriction upon bids is looser, the consequent increased variation in WTP is logically related to the explanatory variable lnVISIT.

Turning to consider the magnitude of bids, it is interesting to note that bid distributions are much less bimodal than in the per-annum studies but are highly related to the payment card ranges presented to each subsample. Figure 4.5 illustrates these points and compares per-visit distributions for our on site survey (upper panel) with those for our remote survey in Norwich (lower panel).

Figure 4.5 Thetford 1 study: WTP response distributions for per-visit evaluations (upper panel = on-site survey; lower panel = remote survey)



Notes: WTPffh = Forest survey, WTP fees (high range payment card: £2-£5)
WTPffl = Forest survey, WTP fees (low range payment card: £0-£3)
WTPnfh = Norwich survey, WTP fees (high range payment card: £2-£5)
WTPnfl = Norwich survey, WTP fees (low range payment card: £0-£3)

This apparent anchoring of responses to the payment card range is also reflected in univariate WTP results which are discussed subsequently in comparison with those from the Norwich per-visit evaluations which we now turn to consider.

B. Remote survey: WTP entrance fees

In one sense asking a group of respondents in Norwich about their WTP entrance fees to Thetford Forest may seem strange in that they might not ever wish to visit the forest. However, our exercise was intended to see to what extent our 'social norms' theory might apply to such a group as well as to see what effect such an increase in the hypothetical nature of CV questions might have. The previous low/high-range payment card effects were also pertinent here.

To a certain extent the entrance fee proposition was not irrelevant to the Norwich per-visit subsamples. In both the low and high-range subsamples over 80% of respondents knew of the forest while nearly 50% had visited it. Interestingly while knowledge of the forest was positively correlated with WTP, as per our respective on-site per-visit samples, visitation rate was negatively related. The best fitting bid functions for the low-range and high-range subsamples are given in equations 4.10 and 4.11 respectively.

$$\underset{}{\ln WTPnfl} = \underset{(5.14)}{0.633} + \underset{(2.43)}{0.331\ KNOW} - \underset{(-3.18)}{0.390\ PENSION} \qquad (4.10)$$

$R^2 = 23.0\%$ $\quad R^2(adj) = 19.8\%$ $\quad n = 50$

$$\ln WTPnfh = \underset{(14.88)}{1.102} + \underset{(2.01)}{0.255\ KNOW} - \underset{(-2.64)}{0.0257\ VISITS} \qquad (4.11)$$

$R^2 = 15.6\%$ $\quad R^2(adj) = 12.0\%$ $\quad n = 50$

where:

lnWTPnfl =	natural log WTP of Norwich per-visit (fee) respondents faced with low range payment card
lnWTPnfh =	natural log WTP of Norwich per visit (fee) respondents faced with high range payment card
KNOW =	1 if respondent knows forest; 0 = otherwise
PENSION =	1 if respondent is of pensionable age; 0 = otherwise
VISITS =	number of visits made by respondent to forest per annum

Tests of multicollinearity confirmed that the inclusion of the KNOW and VISITS variables within equation 4.11 was valid.

Figure 4.5 shows that, as with the forest subsamples, the distribution of bids from Norwich respondents appears to have been strongly anchored within the particular payment card range presented to respondents.

Univariate WTP statistics are discussed in comparison with those from the Thetford Forest per-visit evaluations below.

C. Comparison of Thetford Forest and Norwich entrance fee studies

Socioeconomic analysis of the per-visit subsamples revealed very similar findings to those reported for our per-annum analysis (see table 4.4), namely that respondents in our Thetford Forest subsamples had markedly higher incomes etc., than did those of the Norwich subsamples.

Consideration of the bid distributions illustrated in figures 4.5 and 4.6 clearly shows that the ranges specified on WTP payment cards do significantly affect WTP response. Increasing the bid range used increases mean WTP in a way which we feel invalidates the use of such techniques. Consequently we abandoned the use of payment cards in subsequent research.

Analysis of reported bid functions reveals some interesting findings. We argue that the strength of the constant in all functions (consistently the strongest predictor) suggests that our theory of respondents having a socially influenced notion of a reasonable entrance fee (see chapter 3) has some validity. Other explanatory variables seem logical and consistent with economic theory. However, the considerably weaker nature of bid functions for both Norwich as opposed to both Thetford Forest subsamples, suggests to us that the former group experienced considerably more uncertainty in determining their WTP entrance fees than did the latter. We argue that this arises because of the inherently more hypothetical nature of such questions when asked to the Norwich sample. Although most knew of the forest and had visited it at some time, few were regular visitors. It is likely that this increase in the hypothetical nature of the contingent market and consequent decrease in the likelihood of such respondents actually having to pay such entrance fees, has led to the Norwich respondents overstating their true WTP to the extent that it exceeds that for the respective Thetford Forest subsamples. Given the more affluent socioeconomic characteristics of the Thetford subsamples, this appears to have been a strong effect. We are therefore doubtful of the validity of WTP estimates for the Norwich subsamples. Table 4.7 details univariate WTP results for all the per-visit subsamples.

Table 4.7 Univariate WTP statistics for per-visit evaluations

	n	mean	median	tr. mean	st. dev	se mean	max	Q1	Q3	95% CI	
										lower	upper
FFLOW	50	1.21	1.00	1.17	0.78	0.11	3.00	0.50	1.50	0.99	1.43
FFHI	50	1.55	1.25	1.42	1.29	0.18	5.00	0.50	2.13	1.19	1.92
NFLOW	50	1.45	1.25	1.35	1.01	0.15	5.00	0.69	2.00	1.15	1.75
NFHI	50	2.37	2.00	2.34	1.37	0.19	5.00	1.00	3.13	1.98	2.76

Notes:

FFLOW = Forest subsample, fee (per visit) vehicle, low range payment card
FFHI = Forest subsample, fee (per visit) vehicle, high range payment card
NFLOW = Norwich subsample, fee (per visit) vehicle, low range payment card
NFHI = Norwich subsample, fee (per visit) vehicle, high range payment card

No incomplete/refusal questionnaires
Minimum bid = zero throughout (not excluded from mean)
tr. mean = 5% trimmed mean

iii. Thetford 1 CV studies: conclusions

The Thetford 1 CV studies provided many valuable pointers towards better study design. These are summarised as follows:

1. Choice of payment vehicle can have a significant impact upon respondents' WTP. Despite the apparent attractiveness of a local tax vehicle, when this is politically controversial (as per our poll tax subsample) responses relate to the vehicle rather than the good. However, the direct tax vehicle appears to have worked well.
2. The payment card elicitation method appears to anchor responses within the range shown.
3. The use of per-visit measures for samples with high proportions of respondents who will not be using the resource, appears to seriously reduce the credibility of the contingent market.

Our subsequent studies were designed with these findings in mind. One further suggestions is that per-visit measures may be somewhat subject to influence from 'social norms' regarding appropriate valuations. However, we feel that the Thetford 1 experiment was not sufficiently controlled to convincingly isolate such a finding and therefore did not rule out the use of per-visit questionnaires from subsequent research. We do feel however that further investigation of such a proposition is justifiable.

Regarding our specific results from the CV studies as a whole, we feel that once the caveats raised above are addressed, remaining results appear logical and valid. In particular the relationships between visit rate, visit duration and WTP are interesting. WTP was related positively to visit rate in the per annum studies but negatively in the per-visit studies. This reflects regular visitors having a high total value but relatively low marginal value for visits compared to those of infrequent visitors. Conversely infrequent visitors (proxied by high visit duration) have relatively lower total but higher marginal values than regular visitors. Such a result seems to point to the underlying validity of our experiment once we allow for the biases we have identified in its course.

Our findings from this study concerning the design of CV experiments fed directly into our subsequent CV experiment in the town of Wantage.

4.3.1.2 Thetford 1: ITC Study

The Thetford 1 on-site survey also collected data for an ITC study of woodland recreation values. This was a relatively simple experiment (compared to our subsequent Thetford 2 ITC study) which used OLS[40] estimation techniques to focus upon the impact of changing functional form (and gain experience in conducting ITC work). As even such a simple study involves a complex series of analyses, details are presented along with the survey questionnaire in appendix 2. A brief summary of this work is presented here.

A sample of 129 parties representing approximately 400 individuals was interviewed and data regarding visit distance, cost and duration; substitutes; and socioeconomic variables were elicited. Initial analysis considered the correct specification of the dependent variable for our trip generating function (tgf). A series of correlation and simple regression tests confirmed that a log dependent variable was clearly superior. This decision was not so clear-cut when specification of the cost variable was considered. Leading on from the discussion in chapter 2, all permutation of the travel expenditure and travel time cost definitions detailed in table 4.8 were considered in both linear and log form.

[40]Problems with applying OLS techniques were investigated in detail in the Thetford 2 ITC study.

Table 4.8 Thetford 1 ITC study: travel expenditure and travel time cost definitions (both linear and log linear investigated)

Variable	Definition	Cost
Travel expenditure	1. marginal (petrol) cost	8p/mile
	2. petrol and insurance	23p/mile
	3. full running costs	33p/mile
Travel time cost	1. zero cost (enjoys travel)	0% wage rate
	2. Dept. of Transport rate	43% wage rate
	3. full time cost	100% wage rate

Source: Based upon approach of Willis and Benson (1989) and Benson and Willis (1992). See discussion in chapter 2.

Detailed analysis of the complete set of cost permutations revealed that a marginally superior fit was given by defining a logarithmic cost function (ln COST) as follows:

ln COST = ln (journey cost @ 33p/mile + zero time costs)

A considerable advantage of using a cost function which is not (via time costs) linked to wage rates is that the visitors income may be entered as a separate explanatory variable without inducing collinearity problems.

Further explanatory variables were investigated through stepwise regression analysis of the full range of socioeconomic variables collected in the survey. Of these only the respondents household income proved significant. This finding again echoes the results of earlier UK TC studies (Willis and Benson, 1988; 1989) which report tgfs relating visits to cost and some indicator of socioeconomic status. Equation 4.12 details our best-fitting tgf.

$$\ln VISFOR = \underset{(-1.30)}{-5.548} - \underset{(-8.41)}{0.9422} \ln COST + \underset{(3.50)}{1.0135} \ln INCOME \qquad (4.12)$$

s = 1.378 $R^2 = 45.1\%$ R^2(adj) 44.2% n = 129

where:

lnVISFOR	=	natural log of number of party visits to Thetford Forest per annum
lnCOST	=	cost variable (as previously defined)
lnINCOME	=	natural log of household annual income

All explanatory variables were defined in pence. Figures in brackets are t-statistics.

The overall explanatory power of our tgf is very satisfactory, considerably exceeding that for the Willis and Garrod (1991) ITC studies and higher than all but two of the 22 OLS tgfs reported by Smith and Desvousges (1986) in their ITC studies of water based recreation in the US.

The impact of changing the functional form of the tgf was investigated by estimating semi-log (dependent) and linear models. Table 4.9 details regression equations for all three functional forms as well as giving consumer surplus estimates per party visit and per individual visit. The latter results are subdivided to consider different treatments of child visitors.

The valuation estimates given in Table 4.9 accord well with prior expectations. Clearly mis-specification of functional form leads to significant error in consumer surplus estimates. Furthermore the issue of defining the individual visitor is highlighted by the responsiveness of valuations to alternative definitions. We feel that this is a potentially serious case of confusion and error which has not been properly addressed to date. Our proposed solution, which we adopt in subsequent work, is to concentrate upon the party as the basic unit of valuation thus avoiding subjective decisions regarding individual level values.

Table 4.9 Thetford 1 ITC study: TGFs for three functional forms and corresponding consumer surplus estimates (1990 prices)

Functional form	R^2 adj (%)	Constant		Cost variable		Income variable		CS/party/ visit	CS/person/visit		
		coeff.	t-ratio	coeff.	t-ratio	coeff.	t-ratio	1 child = 1 adult	1 child = 1 adult	1 child = 0.5 adults	children omitted
Double log	44.2	-5.548	-1.30	-0.9422	-8.41	1.0135	3.50	£3.37	£1.07	£1.19	£1.34
Semi log (dep)	39.9	2.3727	6.30	-0.0009490	-7.42	0.00000088	3.56	£7.40	£2.40	£2.67	£3.00
Linear	21.0	28.97	19.86	-0.026719	-3.96	0.00004366	3.34	£27.42	£8.88	£9.87	£11.10

Thetford 1 ITC study: conclusions

This study seems to have succeeded in providing a defensible valuation of woodland recreation. Our best fitting tgf gives a consumer surplus estimate of £3.37 per party visit (£1.07 per individual per visit[41].)

4.3.1.3: Thetford 1 CV/ITC study: conclusions

The Thetford 1 CV provided many important pointers towards improved study design in our subsequent CV work. However, the biases highlighted in this study means that we cannot readily use these estimates for benefit transfer purposes. Conversely our ITC study appears to have worked reasonably well and provides defensible estimates of woodland recreational value.

4.3.2: THE WANTAGE WTP/WTA CV STUDY[42]

This study set out to assess valuations of a proposed (hypothetical) community woodland scheme near to Wantage, Oxfordshire. Specific aims were to determine[43]:

1. The willingness to pay of the local community for the provision of a forest. This was achieved via a household CV study. As the site is presently not available respondents are current potential future rather than current users.
2. The willingness to accept compensation of local farmers on whose land the proposed woodland could feasibly be located, thereby assessing uptake of recreational-access, woodland schemes.

4.3.2.1: Household WTP Survey: methodology

Wantage is a rural town in Oxfordshire with a population of 11,495 adults as recorded in the 1991 electoral register. It is 15 miles from any cities and although there are recreational facilities within this distance there are no nearby open-access woodlands. The

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[41]Treating children and adults equally.

[42]Full details of this study and accompanying analysis are given in appendix 2. The study has been published as Bateman et al. (1996a).

[43]A side issue was to test the feasibility of applying the CV to a small scale planning issue such as this.

town therefore provides a discrete sample population for which some demand for additional recreational facilities is likely.

The survey covered the four census wards of the town, including the connected village of Grove. Out of these areas a stratified sample of 400 households was selected by targeting every twenty-ninth household on the electoral role. This method is consistent with that recommended by Tunstall et al. (1988) in their review of CV sampling procedure. Between July and September of 1991 each selected household was visited and the 'head of household' interviewed[44]. If there was no response on the first visit, the household was revisited on two separate later occasions; the second visit being at a different time of day and, if necessary, a third was carried out at least one week later. Of the 400 households visited, 29 were unobtainable after three visits, a further 37 refused to answer the questionnaire and a further 9 interviews yielded incomplete questionnaires. A useable sample of 325 responses was therefore collected.

Household questionnaire design

An initial questionnaire was tested in a pilot survey of 30 households not selected for use in the main study. The pilot was undertaken in order to:

1. Clarify the meaning of the contingent market description with respect to the respondents' understanding of it, in order to avoid market mis-specification (Mitchell and Carson, 1989). At this point set responses to certain questions regarding the market scenario were developed.
2. Assess the level of non-response to an OE valuation question as a contemporary article had highlighted this as a problem (Eberle and Hayden, 1991). Levels of non-response were found to be acceptable and therefore the format was retained.
3. Assess instrument bias. Initially only an annual trust fund payment vehicle was used. After the pilot a second vehicle, a per-visit entrance fee, was included to provide some comparison.

[44]Problems regarding the definition of "head of household" are recognised. Selection was necessarily a matter for the interviewers discretion and it is not felt that any serious error was incurred here. All those interviewed were at least 18 years of age.

The main survey questionnaire was refined in the light of findings from the pilot and a full copy is given at the end of this section. Initial questions asked respondents how long they had lived in the area. This was both to provide data on a potential explanatory variable and to accustom respondents to the interview process. Subsequent questions asked respondents to name sites of recreation that they had visited on a day trip basis during the last year and to state their preferences with respect to urban or rural sites. These questions were included to encourage consideration of preferences for competing recreation facilities and to establish a measure of familiarity with the proposed good.

Following this the contingent market and payment vehicle were introduced via a 'constant information statement' which was read out verbatim to all respondents. Households were then asked whether or not they would be prepared to pay towards provision of the wood. Such a 'payment principle' question was included mainly as a way of validating zero bids as it was felt that directly presenting respondents with a WTP question might intimidate those who hold zero values (Harris et al., 1989). Respondents who answered 'no' to this question were asked to state their reasons for such a response whilst those who answered positively were asked the WTP questions[45].

Two WTP questions were used. Firstly respondents were asked how much they were WTP per household per annum (referred to subsequently as the 'per-annum' question). Secondly, respondents were then asked how much they would be WTP per adult per visit as a car parking fee (referred to subsequently as the 'per-visit' question). Here then all respondents who were WTP some amount were presented with, in turn, both the annual and per-visit format question. Ideally we would want to either use separate samples for each format or vary the order in which questions are presented so that any ordering or anchoring effects might be assessed. However such an analysis was not undertaken because we were a-priori uncertain of obtaining sufficient sample size (this problem was rectified in the subsequent Thetford 2 study).

After the valuation questions, respondents were asked to assess their expected use of such a woodland. This was included both to provide a potential explanatory variable for analysis of the bid function and to indicate the level of use and of non-use valuation included in willingness to pay figures. This indirect method was considered preferable to asking

[45]It was subsequently felt that the motivations behind positive responses should also be investigated and such an analysis was built into the Thetford 2 CV experiment.

respondents to divide their valuation into subcategories of existence, use and option value (as per Loomis et al., 1984) which we considered to be a highly suspect procedure liable to allow respondents to inflate the altruistic motivations of their valuations.

Finally all respondents were asked questions regarding their household characteristics in order to establish socioeconomic factors affecting willingness to pay.

4.3.2.2: Farm WTA survey: methodology

The study also examined the levels of payment required by local farmers for them to undertake the proposed woodland scheme i.e. their WTA compensation. The relatively small local farming population posed an immediate problem regarding sample size.

Farm addresses were taken from the local telephone directory. Initially addresses were restricted to those within a three mile radius of the town in order to maintain consistency with the scenario presented in the household survey. However, this failed to produce an acceptable sample size and a six-mile radius was finally adopted. Just over forty farms were contacted by mail to request a face to face interview. A considerable proportion of farms refused to be interviewed, the main reason being that, as interviews coincided with the harvest season (the surveys being conducted between July and October 1991), farmers faced heavy workloads and were not available for interview[46]. Because such refusals were for reasons unconnected with the content of the questionnaires (as distinct from say household refusals to pay for woodland) the farmer participation rate is not seen as a serious problem for the validity of the survey. In total nineteen farm interviews were completed. Whilst we recognise and accept problems regarding such a sample size, we would highlight the difficulty of assembling a large sample here and feel that the results can be accepted as generally indicative of farmers attitudes.

<u>Farm questionnaire design</u>

Due to the limited availability of respondents it was impossible to conduct a pilot survey of farms. Initial questions were related to the value of present agricultural production and associated costs. This data provided a comparison between the expressed value of the woodland as given in the household survey, and the current value due to agricultural

[46]A second reason, given by four farmers, was that they had already participated in other research surveys and were unwilling to devote further time.

production. Furthermore, by initially establishing the value of the land on the farm, it was hoped to focus the farmer's attention on an acceptable and reasonable level of compensation for income loss due to the removal of land from present production. Such an approach was designed to minimise any tendency to overstate compensation requirements. After these questions the contingent market and payment conditions were introduced to the respondent in the following manner:

> "The purpose of this survey is to assess the feasibility in this region of planting an area of mixed woodland for recreational purposes. As you may know, under the Farm Woodland Scheme the government provides grants for planting areas of at least 3 hectares on farms. The scheme being examined in this survey would allow participating farmers to take up these grants, but in addition to receive further payments from a local woodland trust. These extra payments would be conditional on the woodland being accessible to the public (with a small area allocated for parking space). The land would remain your property but you or your subcontractor would be expected to provide basic maintenance."

This scenario proved to be similar to that embodied in the Forestry Commission's subsequent Community Woodland Scheme.

The respondents were then asked to state a minimum level in pounds per annum per hectare (or acre), which would be acceptable to them in order to commit land into such a scheme. They were also asked how much land they would allocate to the scheme at the payment level stated. It should be noted that respondents were not told the payment levels available under existing schemes. This was in order to avoid the possibility of such information providing an anchoring point for the valuations given. However, it was clear from the interviews that some of the farmers had prior knowledge of the scheme and levels of payment and this may have affected responses.

4.3.2.3: Household survey: results

i. Household characteristics

Questions regarding length of residence revealed that less than 5% of the sample had lived in Wantage for one year or less. The mean age of residence was 18.5 years. This distribution was somewhat skewed with a 5% trimmed mean of 17 years and median residency of 14 years. The overall picture indicated a high degree of familiarity with the local environment.

Respondents were invited to list up to four recreation sites which they had visited over the past year and state average annual frequency of visits to stated sites. Responses were subsequently classified into three categories of recreation attraction: urban; park (i.e. non-urban attractions with entrance fees); and rural (open access). Responses indicate a significantly higher frequency of visit to rural sites (a mean of over 8 visits/household p.a.) than either urban or park sites (means of 2.0 and 2.6 visits respectively). This trend was borne out by a direct question asking households whether, given the choice, they would prefer to visit a rural (outdoor) or an urban (indoor) recreation site. 298 of the 325 households surveyed (92%) stated that they would prefer to visit a rural/outdoor site leaving just 27 households (8%) stating a preference for an urban/indoor site.

Following the WTP questions (discussed subsequently[47]), respondents were asked to predict how often they would visit the proposed wood annually. Only 11 households (3.4%) stated that they would not visit the wood. Mean predicted visitation frequency was just under 15.

Comparison of responses regarding existing recreation visits and expected visits to the proposed woodland revealed that predicted demand for the wood is relatively high. Whilst some of this difference may be due to over-enthusiasm in favour of provision[48], and there is clearly a rounding effect in predicting visits, this does demonstrate a very significant demand for the proposed wood. This is perhaps not surprising given the notable absence of open access public space in the locality, particularly of quality rural land.

Data detailing household composition by age was also collected. Observations were categorised into groups roughly corresponding to economic dependency criteria (i.e. pre-school, school, young/mid/older income-earners, pensionable) and these categories proved useful in the subsequent bid curve analysis. If adjustment is made to recombine these categories into constant width age bands we observe the expected roughly domed distribution typical of a stratified sample.

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[47]The questionnaire is reproduced as part of the detailed discussion of this study in appendix 2.

[48]Analogous to the subsequently discussed phenomena of strategic overbidding in responses to WTP questions.

Finally data was gathered regarding the economic characteristics of households. Principle amongst these variables was household income[49]. Assurances of confidentiality and the use of information cards employing alphabetical income categories, appear to have allayed any resistance to providing such information and a 100% response rate was achieved on this question[50]. Sample income was found to approximate a normal distribution about the median £15,000-£19,999 category.

ii. Refusals to pay

Prior to both the annual and per-visit format WTP questions, respondents were asked whether they were, in principle, WTP some amount for the proposed woodland. This question was included primarily to validate a zero bid as it was felt that, in the absence of such a question, asking respondents for their WTP might inhibit such bids and upwardly bias mean WTP. Such an approach accords with the emphasis upon 'conservative design' which underpins the NOAA 'blue ribbon' survey design protocol (Arrow et al., 1993). All those who responded negatively regarding the principle of payment were asked to specify their motivations for such a response. Details of these reasons and overall refusal rates are given in table 4.10.

Table 4.10 indicates a relatively high refusal rate regarding the annual WTP question (24.3%). However, as an economic constraint (insufficient income, etc) was by far the prime motivation for refusal, such zero WTP sums do not pose a theoretical problem. The residual refusals for this format include three respondents who indicated an 'extreme free-riding' incentive as their underlying motivation. Such a strategy was expected to occur to some extent. The indicated level is not excessive and is indeed considerably lower than that observed in large scale user studies (Bateman et al., 1992). Those respondents who refuse to bid upon the grounds that the woodland should be open access could arguably be interpreted as articulating a fundamental objection to the entire principle of the economic appraisal of projects (not just monetary evaluation of environmental preferences), arguing instead for a policy-led approach to decision making. If such responses were widespread they

[49]Data was also gathered regarding professional and employment status. However, a logical categorisation of this data was not satisfactorily achieved and the information was not used in bid curve analysis.

[50]We view this as a good test of questionnaire design. Similarly, Bateman et al. (1992) record only a 6% refusal rate for a similar question in a face to face interview situation.

might provide a serious criticism of the basis of this study. However, the observed scarcity of such responses can be interpreted as a counter-argument that individuals recognise the need to allocate finite resources in an economically efficient manner.

Table 4.10: Refusal reasons and refusal rates for annual and per-visit WTP formats

Reason for refusal	Annual WTP No.	%	Per-visit WTP No.	%
Insufficient income or other economic constraint	70	21.5	37	11.4
Access to woodland should be free	5	1.5	11	3.4
The Government should pay	3	0.9	0	0.0
The land should remain in agriculture	1	0.3	0	0.0
Total refusal numbers/rate	79	24.3	48	14.8

Note: Percentages are based upon the entire sample of 325 households (all respondents presented with both WTP formats).

The lower refusal rate for the per-visit format might be interpreted as reflecting a wider acceptance of use-related entrance fees over the more general annual payment vehicle. Whilst we suspect that the difference between refusal rates for the two formats is likely to be statistically insignificant, it could simply be argued that respondents are expressing a preference for use-related entrance fees rather than annual donations which, amongst other attributes, are likely to be less sensitive to usage. A second, less favourable, interpretation could be that, as our sample will include households who do not enjoy woodland recreation and would not visit the site, the entrance fee vehicle allows such households to state a per-visit WTP sum (where they are unwilling to pay an annual fee) in the knowledge that, as non-visitors they will also ultimately be non-payers. If such logic does describe a significant proportion of the sample then we should have less faith in positive responses to the per-visit entrance fee question. It is notable that not one household stated that its reason for refusing to pay was that it had no intention of visiting. Given that it is likely that some such households were interviewed, this heightens concerns regarding the per-visit measure. Such a conclusion needs to be tempered by the observation that, within stated reasons for refusal, the majority centred upon economic constraints which themselves pose no theoretical problems.

iii. Mean WTP and analysis of distributions

The Wantage CV study used open-ended (OE) elicitation methods. In the light of our research into the effects of switching elicitation technique (see our Norfolk Broads study discussed at the start of this chapter) this seems a valid approach although our findings indicate that OE questions may elicit lower bound estimates of WTP. Given a general desire for conservative design in CV studies (Arrow et al., 1993) this seems a potentially desirable feature of this study. Accepting these riders, table 4.11 gives univariate WTP statistics for responses to the two formats.

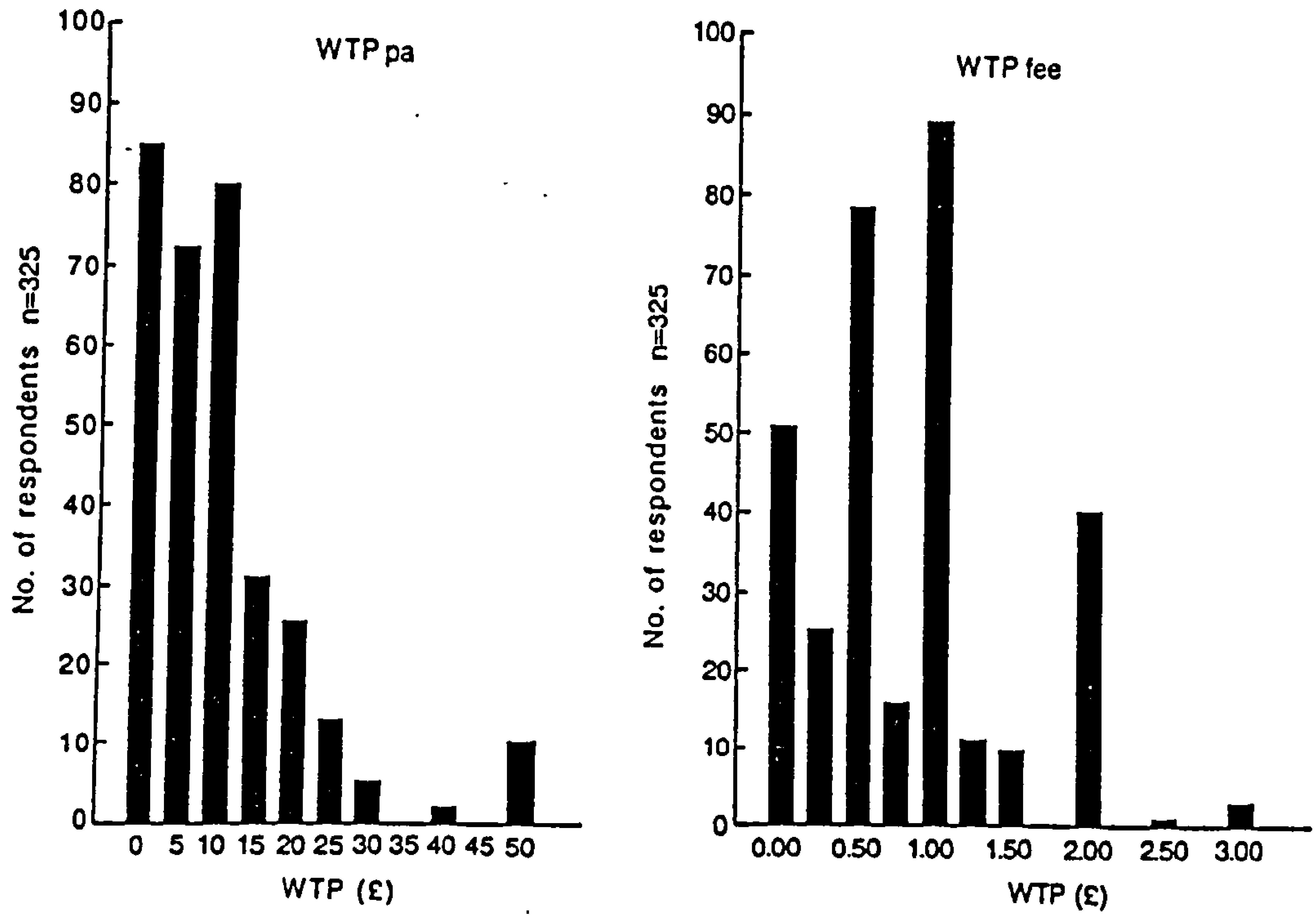
Table 4.11: Summary WTP results (£'s): per-annum (WTPpa) and per-visit (WTPfee) formats

Format	n	mean	median	tr.mean	st.dev	se.mean	max	Q1	Q3
WTPpa	325	9.94	10.00	8.64	10.66	0.591	50.00	2.00	15.00
WTPfee	325	0.82	0.75	0.79	0.64	0.036	3.00	0.50	1.00

Note: All values in 1991 prices. Minimum bid = zero for both formats (included in calculation of mean etc.).

Figure 4.6 illustrates WTP response distribution for both the annual and per visit questions. All refusals to pay are included as zeros. At first glance there may appear to be certain fundamental differences between the distributions illustrated in figure 4.6, with the annual responses seemingly more skewed than the per-visit values. Furthermore, whilst the per-annum distribution appears smoothly declining as values increase the per-visit distribution appears to be clumped upon certain round figures (50p, £1, £2, etc). However, upon closer inspection these distributions exhibit some similarities. The characteristic of respondents giving round number answers in the per-visit scenario is, to some extent, repeated in the annual sum experiment where responses were typically £5, £10, etc. although examination of the overall distributions shows that this rounding effect is more pronounced in the per-visit format question.

Figure 4.6: Response distributions for annual and per-visit format WTP question (WTPpa and WTPfee respectively).



a) 'Warm-glow' altruism

Further examination of the two distributions shows that, examining non-zero bids, both exhibit an initial increase in 'positive' responses as the WTP level increases from zero to some relatively low amount after which the distributions tail off. This trend has been observed elsewhere (Bateman et al., 1992) and may indicate an effect similar to the 'warm-glow giving' phenomena proposed by Andreoni (1990) or the 'purchase of moral satisfaction' idea put forward by Kahneman and Knetsch (1992).

Andreoni (1990) discusses the concept of 'impure altruism' whereby individuals donate to charitable good-causes so that they can enjoy a 'warm-glow' of giving. Therefore, in answering our questionnaire, certain respondents may state some (probably small) bid for warm-glow reasons. This poses no problem provided that such respondents are genuinely prepared to pay the amounts stated. However, it may be that some respondents see the CV hypothetical scenario as an opportunity to endow themselves with a warm-glow satisfaction at no cost. Such respondents will be unwilling to state a true WTP of zero and will prefer to state some (again probably small) bid.[51] A related issue here is that some respondents may have an aversion to stating a zero response. Motivations for such a response are many and complex but centre upon the interactive interview process. Orne (1962) discusses the 'good respondent' who attempts to please the interviewer by stating what they perceive as a 'correct' answer. A zero bid is unlikely to be thought to conform to such specifications. Similarly the respondent may hold the interviewer in high esteem and again 'try to please'. A further motivation may be the desire (either conscious or subconscious) to conform to a 'social norm' WTP as discussed in chapter 3.

All the above motivations are liable to lead respondents who would not actually pay away from a zero stated bid and towards one which arises from the interview mechanism. Such a response cannot necessarily be attached to the specific good in question i.e. we could change the good for any similar scale 'good cause' and those individuals concerned (note, not all respondents) would still give the same response[52].

Whilst it was not possible, without adopting extended psychological testing, to identify such 'warm-glow' bidders, a simple analysis was undertaken to examine the implication of such strategies. Here we assumed that all bids below a certain level fell into the 'warm-glow' category. This is clearly a crude approach but one which was dictated by limited resources. The distribution of bids under both formats were examined for evidence of any appropriate cut-off point. The rounding of bids observed earlier suggested certain low category amounts which respondents might choose to give under 'warm-glow' bidding. For the annual format let us assume that the relevant bid threshold is £5 p.a. whilst for the per-visit question we can assume a threshold of £0.50. We can now recalculate mean WTP by setting all bids up to and including these thresholds to zero. Table 4.12 details the results of such an analysis.

Table 4.12 indicates that, for both formats, even if we adopt the very strong assumption that all bids up to and including the chosen threshold are 'warm-glow' responses and (again, a strong assumption) should really be zeros, then this makes relatively little difference to the estimated mean, which declines 11% for the annual format and 17% for the per-visit format. We would suggest that such assumptions are, in fact, too strong as they omit

[51]This problem will be compounded by rounding effects which, as Bateman et al. (1995a) argue, are likely to operate in a generally upward direction.

[52]In short, such respondents would state such a bid for any similar good cause, i.e. woodlands, the dogs'-home, the donkey-sanctuary, etc.

bids which are significantly non-zero.

Table 4.12: Impact upon estimated means of truncating potential 'warm-glow' bids

WTP format	truncation option[1]	mean WTP (£)	median WTP (£)	st. dev.
Annual	untruncated	9.94	10.00	10.66
	truncated	8.85	10.00	11.36
Per Visit	untruncated	0.82	0.75	0.64
	truncated	0.68	0.75	0.63

Note: 1. Untruncated = all bids included as received. Truncated = all per annum bids up to £5 (inclusive) set to zero; all per visit bids up to £0.50 (inclusive) set to zero. All refusals to pay are included as zero's (n=325 throughout).

We conclude then that although 'warm-glow' bidding may be a feature of this and other CV surveys, with regard to this study the impact of any such tendency is not severe.

b) Free riding

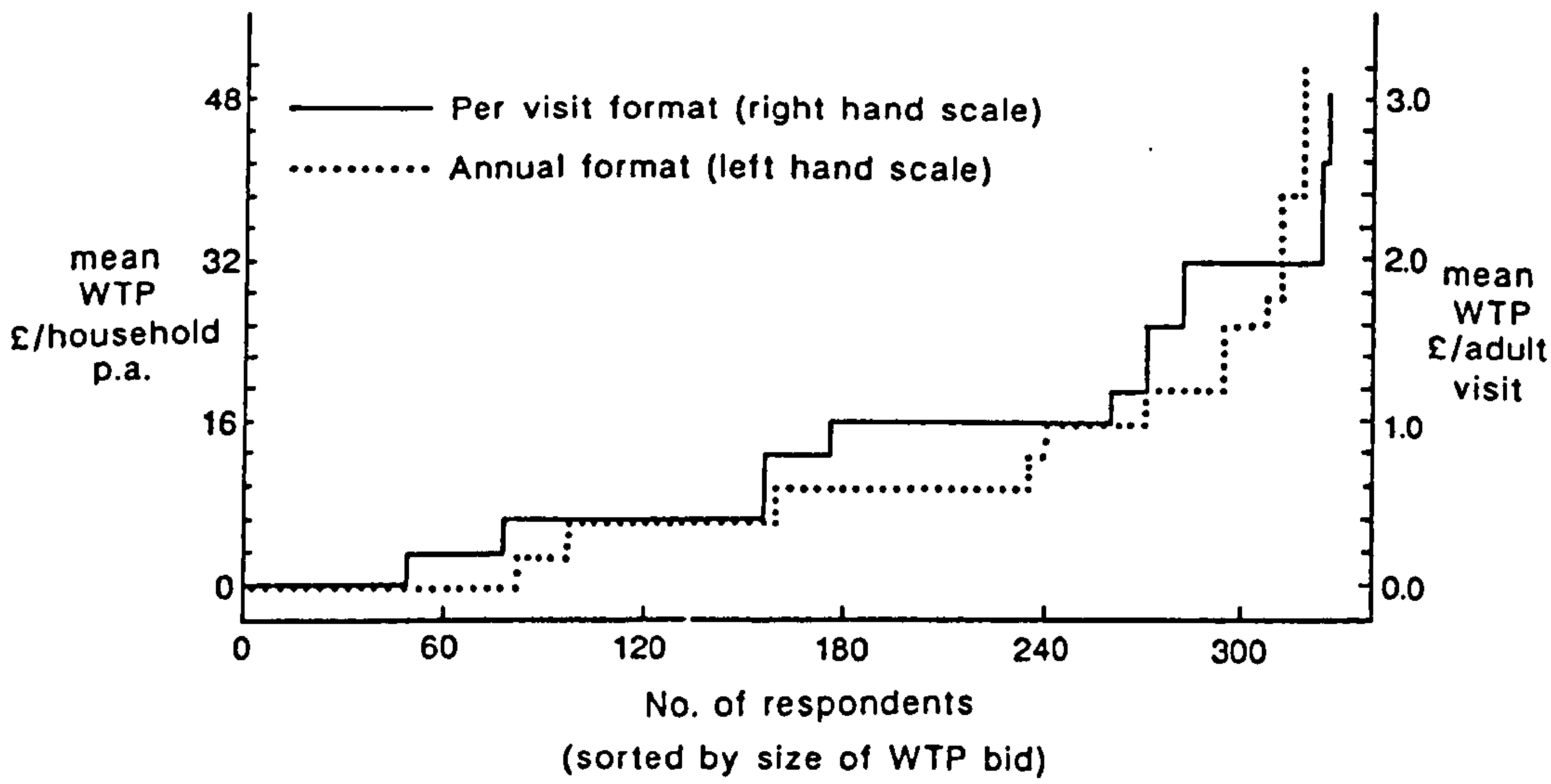
The non-woodland research discussed at the start of this chapter suggests that free rider incentives may somewhat reduce WTP responses to OE questions. We have stated in our analysis of refusals to pay that extreme free-riding does not appear to be particularly evident in this study. However, less extreme free-riding, in the form of a downward revision of bids may operate within non-zero bids so as to reduce mean WTP. If both a 'warm glow' and 'free-riding' effect are in operation then these would act in opposite directions. However, to suggest that such effects might be self-cancelling would, on the basis of the paucity of evidence to hand, be seriously premature. All we can conclude is that either or both effects may be in operation to uncertain degrees.

c) Strategic overbidding

Chapter 2 discussed the possibility of certain respondents overstating their true WTP for strategic reasons. Extreme strategic overbidding will be evidenced by upper tail outliers and a consequent high responsiveness in mean WTP to their omission. In Figure 4.7 WTP responses have been sorted from lowest to highest along the horizontal axis showing that for both payment vehicles, a few relatively high responses were recorded.

Consideration of figure 4.7 suggests that, if strategic overbidding is present, then it is confined to a relatively small number of respondents. In both the per-annum and per-visit formats, omission of the very highest few bids does cause the mean to fall rapidly, suggesting these are the extreme outliers indicative of strategic overbidding. However, the rate of decline slows rapidly once these most extreme bids have been removed. Clearly at some point we move from bids which are high because of (possibly) strategic behaviour, to bids which are high because of the interaction of preferences and ability to pay. If we assume that strategic overbidding can be identified by very disproportionately high bids, then figure 4.7 suggests that there are relatively few of these. We therefore conclude that strategic overbidding may occur in a small minority of cases. The impact of such bids will be relatively high and, may be responsible for inflating per-visit mean WTP by perhaps 10% and per-annum mean WTP by anything up to 20% although, without carefully designed, specific experimentation, such estimates are merely ballpark figures.

Figure 4.7: Potential strategic overbidding responses



The result that per-visit values seem less responses to upper bid truncation could be taken as indicating that answers to this format are more resistant to strategic behaviour. However, an alternative explanation follows our 'social norms' hypothesis discussed in chapter 3. If responses to per-visit questions relate more to a notion of a 'reasonable' entrance fee amount than to true WTP then this would account for the apparent relative lack of strategic behaviour but in turn question the validity of such an approach.

c) Bid curve analysis

Validity testing was undertaken in part through bid curve analysis. The socioeconomic and preference data collected in the survey was related to both linear and log-linear specifications of the per-annum and per-visit WTP response.

c.i) The per-annum responses (WTPpa)

Analysis showed that a log-linear specification of the dependent variable WTPpa performed significantly better than linear versions. Table 4.13 reports results from a forward-entry stepwise regression analysis relating the log-linear dependent variable. lnWTPpa, to significant explanatory variables.

Table 4.13: Stepwise regression of lnWTPpa on 34 predictors

Step	1	2	3	4	5	6
Constant	-5.397	-5.335	-5.096	-4.418	-4.214	-4.374
lnINCOME t-ratio	0.755 9.79	0.726 9.56	0.683 9.06	0.683 9.16	0.647 8.54	0.630 8.33
lnRURVIS t-ratio		0.165 3.78	0.160 3.74	0.140 3.25	0.156 3.61	0.131 2.98
lnPKVIS t-ratio			0.246 3.69	0.227 3.43	0.239 3.62	0.235 3.59
PREFTOWN t-ratio				-0.59 -2.90	-0.56 -2.75	-0.52 -2.58
AGE 17-25 t-ratio					0.167 2.32	0.173 2.42
lnVISWOOD t-ratio						0.140 2.34
S	1.04	1.02	1.00	0.992	0.985	0.978
R^2	22.87	26.14	29.15	30.96	32.11	33.26

Notes: n = 325. Variable definitions as follows:

lnWTPpa	=	natural logarithm of households annual WTP (£)
lnINCOME	=	natural logarithm of households gross annual income
lnRURVIS	=	natural logarithm of number of visits made by household to rural sites per annum
lnPKVIS	=	natural logarithm of number of visits made to parks
PREFTOWN	=	1 if prefers town-based recreation; = O otherwise
AGE17-25	=	number of persons in household aged 17-25 years
lnVISWOOD	=	natural logarithm of households predicted number of annual visits to proposed wood

The final equation reported in table 4.13 contains certain explanatory variables which we might expect to be collinear. However, inspection of coefficient values across steps does not immediately reveal any obvious severe problems as they remain fairly stable.

Explicit tests for multicollinearity suggested that only the correlation between lnRURVIS and lnVISWOOD gave any real cause for concern. Accordingly the latter variable was dropped from our best-fit model which is reported as equation 4.13.

$$\ln WTPpa = \underset{(-6.70)}{-4.77} + \underset{(8.54)}{0.647} \ln INCOME + \underset{(3.61)}{0.156} \ln RURVIS$$

$$+\underset{(3.62)}{0.239} \ln PKVIS \underset{(-2.75)}{-0.556} PREFTOWN + \underset{(2.32)}{0.167} AGE\ 17\text{-}25 \qquad (4.13)$$

$R^2 = 32.1\%$ $R^2(adj) = 31.0\%$ $n = 325$
Regression $F = 30.17$ ($p = 0.000$)

The bid curve model given in equation 4.13 fits the data well in comparison to most CV studies employing OE elicitation methods and satisfies the more stringent guidelines on theoretical validity testing (Mitchell and Carson, 1989; Bateman and Turner, 1993). More importantly the relationships suggested by individual explanatory variables are highly significant and in accord with a-priori expectations. It appears that household income is the most dominant consideration affecting responses to the per-annum WTP question. Responses are also positively linked to visits to rural or town park recreation sites while those who prefer town-based leisure pursuits exhibit significantly lower levels of WTP. A final interesting factor is the positive influence upon WTP exerted by the presence of household members between the ages of 17 and 25. This may be due either to higher recreation demand or to an enhanced environmental awareness amongst this group.

In summary the per-annum study appears to have elicited theoretically consistent WTP responses.

c.ii) The per-visit responses (WTP fee)

Per-visit WTP responses question were much less firmly linked to standard explanatory variables than were the WTPpa bids. Regression analysis of the bid curve for per-visit responses confirmed this observation. While a log-linear dependent variable provided a best fit of the data, the resulting bid curve model, detailed in equation 4.14, exhibits a very low degree of overall explanatory power.

$$LnWTP_{fee} = \underset{(25.33)}{0.595} - \underset{(-3.94)}{0.135} PENSION - \underset{(-2.26)}{0.00175} VISWOOD \qquad (4.14)$$

$R^2 = 5.7\%$ R^2 (adj) $= 5.1\%$ $n = 325$
Regression $F = 9.76$ ($p = 0.000$)

where

$\ln WTP_{fee}$	=	natural logarithm of stated WTP per visit
PENSION	=	number in household aged 65 years or over
VISWOOD	=	predicted number of household visits to the proposed wood per annum

The equation given in equation 4.14 takes a semi-log (dependent) functional form. Explanatory variable relationships are as expected. The negative sign on PENSION accords with the expected lower visitation rate and ability to pay of this age group. The negative sign on VISWOOD reinforces the relationship, observed in our Thetford 1 per-visit survey, of responses indicating that regular visitors are more resistant to the per-visit payment vehicle than are occasional visitors. These factors provide the strongest support for the validity of our per-visit results. However, contrary evidence is suggested both by the poor overall fit of this model and the very strong nature of the constant. We believe that this latter factor provides further evidence for our contention that per-visit WTP responses are affected by social norm factors.

iv. Summary results: household WTP studies

It seems that responses to the per-annum WTP questions were strongly linked to expected explanatory variables and therefore pass a simple test of theoretical validity[53]. Responses to per-visit format questions were less strongly linked to such factors and, while they may still have some justification as magnitude estimates, these results seem to support our social norm hypothesis.

Convergent validity testing (see chapter 2) was not feasible for our per-annum format as no directly comparable (remote survey) woodland studies exist within the UK literature. However, a within-format comparison across several different types of outdoor recreation resources showed that the above WTPpa mean was logically related to the substitutability, uniqueness and provision change factors which seemed to determine WTP results for a sample of over thirty studies (Bateman, Willis et al., 1994).

Cross-study comparison of our WTPfee result was easier given the relatively high numbers of comparable studies in the literature. Our WTPfee mean falls above but well within one standard deviation of the mean of all other comparable UK studies[54].

[53]In effect, responses were in logical accordance with economic theory. Wider questions regarding the overall validity of CV responses (as reviewed in chapter 2) may still apply.

[54]Mean of other per-visit OE use value studies = £0.63; st.dev = £0.25. Full details of cross-study analysis are given in chapter 3.

4.3.2.4: Farm survey: results

Responses were elicited from nineteen farmers using face to face interview techniques. Whilst we have already recognised problems associated with inferring from small sample sizes, eliciting even this sample proved difficult given the necessary steps to secure each interview during the harvest season. We have no reason to suppose that those interviewed formed a biased sample and therefore report percentage responses (as well as numbers) as an approximate guide to expected farmer attitudes in similar areas[55].

i. Farm characteristics

The interview opened with questions regarding the general characteristics of the farm. Specifically farmers were asked to state the agricultural land use; farm tenure; and average profit per acre (or hectare). Table 4.14 details individual farm responses to these and certain other questions.

Most farms (10 farms, equivalent to 53% of the total sample) were mixed agricultural producers combining arable with a variety of other standard activities. The remainder of the sample consisted mainly of purely arable producers (7 farms; 37%), one purely dairy farm and one farm entirely in setaside (5% each) completed the sample. Nearly all those interviewed owned their farms (17 farms; 90%). This may limit the applicability of results to rented tenure farms.

Farmers were asked to state their average profit[56] per acre under existing production. This was asked so as to encourage farmers to sensibly consider the immediately following question regarding acceptable levels of financial compensation and to allow a comparison between these two amounts. Mean stated profit was £125/acre (£309/ha). Individual stated profit varied considerably between farms[57]. This may be due in some measure to an unwillingness to reveal profits to the interviewer (three farmers (16%) refused to answer this question which in turn may indicate a wider understatement of true profit). However, it was felt that the majority of this variation was due to changes in economic efficiency and consequent productivity across farms.

[55] We would expect participation rates to rise as per-acre agricultural incomes fall. Such conditions would apply to our subsequent studies of Welsh hill farms.

[56] The simple term 'profit' was preferred to any more technical definition.

[57] Although only one farm lies (just) outside the 95% confidence internal around the mean.

Table 4.14: Farm characteristics and farmers' willingness to accept compensation for transferring from present output to woodland

Farm	Land use	Tenure	Profit/acre (hectare)	WTA/acre (hectare)	Allocation acres (ha)	Reason for non-allocation
1	Arable/ Sheep	Owned	£100 (£247)	£250 (£618)	0	Land should be used to produce food
2	Arable/ Beef	Owned	——	£20,000 (£49,440)	0	Does not like government policy
3	Arable/ Dairy	Owned	£125 (£309)	£300 (£741)	0	Does not want public access to the farm
4	Arable	Owned	£30 (£74)	£200 (£494)	5 (2)	——
5	Arable	Owned	£105 (£260)	£250 (£618)	30 (12)	——
6	Arable	Owned	£45 (£74)	£150 (£370)	2 (0.8)	——
7	Arable/ Beef/Lamb	Owned	£130 (£321)	——	0	Does not want public access to the farm
8	Arable	Owned	——	——	0	Land not suitable to grow trees upon
9	Dairy	Rented	£85 (£210)	——	0	Does not want public access to the farm
10	Arable	Owned	£116 (£287)	£300 (£741)	0	Farm too small for the scheme
11	Arable/ Setaside	Owned	£100 (£247)	——	0	Does not want public access to the farm
12	Arable/ Beef	Owned	£186 (£459)	£100 (£247)	125 (50)	——
13	Arable/ Dairy	Owned	£186 (459)	£200 (£494)	100 (40)	——
14	Arable/ Pigs	Owned	£163 (£402)	£250 (£618)	20 (8)	——
15	Arable/ Beef	Rented	£150 (£370)	£250 (£618)	0	Does not want public access to the farm
16	Arable	Owned	£280 (£692)	£600 (£1,483)	3 (1.2)	——
17	Arable	Owned	£145 (358)	£150 (£370)	0	Farm too small for scheme
18	Arable/ Dairy	Owned	£140 (£346)	——	0	Farmer too old to undertake long-term project
19	Setaside	Owned	——	£250 (£617)	0	Unwilling to undertake another scheme to Setaside
Total			£130 (£321)	£250 (£617)		
Mean			£57 (£141)	£121 (£300)	15 (6)	

ii. Willingness to allocate land to the woodland project

Twelve farmers (63%) initially stated that they were unwilling to allocate land for public access recreational woodland. Of these the most commonly stated reason for refusal was that the farmer did not want to allow public access to the farm (5 farms or 42% of those refusing to enter the scheme). Concerns regarding a loss of rights following entrance to such a scheme may be well founded. Repeated public use of footpaths within a wood may lead to their classification as public rights of way. Furthermore, interviews with senior Forestry Commission staff revealed that current policy will not allow farmers to be granted felling licences unless equivalent areas of replanting are agreed[58]. In other words the decision to allocate a certain area from agriculture into recreational forestry may well be irreversible. Such irreversibility may perversely prove to be a considerable block to the extension of agro-forestry. Other reasons for refusing to participation can be broadly classified as 3 (25%) which were farm specific (farm size or land type); 2 (17%) which disliked the particular policy; and 2 (17%) which reflected the farmers particular preferences. These categorisations might have classified the outcome of these interviews somewhat differently. However, as a rough indication we feel that this is acceptable. It is notable that both of the rented tenure farms declined to allocate land to the scheme[59]. This may be because farmers felt that permission would have to be sought from the owners (which is a legal requirement) or a greater disinclination towards delayed return schemes. However, the sample size precludes any firm conclusion being drawn.

Seven farmers (37%) were initially willing to allocate land to the recreational woodland scheme. Given concerns regarding public access this was felt to be an encouragingly high percentage rate. Mean allocation was just over 40 acres (just over 15 hectares) per participating farm. This mean falls to approximately 15 acres (about 6 hectares) if non-participating farms are also taken into consideration. Uptake amongst participating farms appears to be bimodally distributed with two farms willing to allocate 100 acres or more into woodland and the remainder only willing to undertake small scale afforestation projects. Whilst grant aiding is available for small scale schemes, if the objective is to provide a viable, discrete recreational area then such small pockets (unless they can be combined) may not be suitable. Nevertheless the agreement to large scale planting by two

[58]Interview with Chief Forester, Santon Downham, Thetford Forest, 1993.
[59]Subsequent analysis (see table A2.39) confirmed this as a statistically significant relationship.

farmers is encouraging particularly where the objective (as under the Forestry Commission Community Woodland Scheme)[60] is simply to ensure that the local community has access to a woodland recreation site within five miles of the community centre.

iii. Willingness to accept compensation

The majority of interviewees (14 farms; 74%) stated a sum which they would be willing to accept in annual compensation for allocating land out of agriculture and into public access woodland (WTApa). This included 7 of those farms who initially rejected the principle of such allocation (58%). This latter result seems to indicate that, if the price was right, such farms would consider a move out of conventional agriculture. However, there is one very noticeable 'protest bid'[61] amongst this subsample which at £20,000/acre is not only more than 150 standard deviations above the mean and more than 30 times larger than the next highest bid, but is also likely to be of equal magnitude to the entire annual net farm income. It is feasible that this respondent had in mind a discounted total net present value sum for the entirety of the project, in which case such a response would be reasonable. However, given that no other respondents gave answers within even the same magnitude, we feel that such an explanation is unlikely and a protest strategy seems much more likely.

Excluding this one outlier, the mean stated WTApa is £250/acre (£617/ha). Restricting the sample to those who initially stated an area which they were willing to allocate into the scheme has no effect upon this result, adding support to the validity of non-allocators responses (and thereby the entire sample)[62] as being valid bids.

Modelling WTApa

Analysis of responses showed that stated compensation levels were strongly related to both existing profit levels and the overall size of the farm. No further significant explanatory variables were identified and the best fitting regression model of WTApa is given in equation 4.15:

[60]See discussion of grant schemes in chapter 6.

[61]The author dislikes the general application of this term to anyone who does not give an expected answer to a bidding (WTP or WTA) question. However, this particular respondent must satisfy all relevant requirements of an archetypal 'protester'.

[62]Excluding the single 'protest' bid.

$$\text{WTApa} = \underset{(1.81)}{94.04} + \underset{(4.04)}{1.48}\ \text{PROFIT} - \underset{(-3.37)}{1.93}\ \text{ACRES} \tag{4.15}$$

$R^2 = 69.9\%$ $R^2\,(adj) = 63.2\%$ $n = 13$
Regression F = 10.43 (p = 0.005)

where

WTApa	=	Farmers required compensation (£/acre) for entering the woodland scheme
PROFIT	=	Level of profit under existing agriculture (£/acre)
ACRES	=	The number of acres which the farm is prepared to allocate into the woodland scheme.

The model presented in equation 4.15 fits the data well and reports logical relationships between the dependent and explanatory variables. Farms with higher profit levels from existing activities demand higher levels of compensation for entering the woodland scheme. Furthermore those who are only willing to consider small scale planting require higher per-acre payments. This implies, logically, that large scale plantations, which presumably will benefit from economies of scale, are considered viable alternatives at a relatively lower per-acre subsidy rate than small scale woodlands.

The area of land which farmers were prepared to allocate into woodland was positively related to overall farm size and thence to per acre profit levels so that a significant correlation exists between PROFIT and ACRES ($r = 0.359$). Stepwise analysis indicated that this has caused a significant increase in the coefficient and t-value on the PROFIT variable. We cannot therefore place too much faith in the precise coefficient estimates given in equation 4.15. However, the observed multicollinearity is not strong enough to make such estimates invalid, rather they should be treated as having wide confidence intervals.

The degree of explanation of the WTA bid curve is not affected by collinearity between explanatory variables. Even allowing for the small sample size, the degree of fit is exceptionally high for an OE CV study, particularly as this survey employed a WTA question. We can conclude that farmers' responses were highly logically consistent and accord with economic theory. This funding runs contrary to most WTA studies and we consider reasons why this may be so subsequently.

4.3.2.5: Wantage CV WTP/WTA study: discussion and conclusions

i. Theoretical welfare measures

This study has asked two separate questions. Firstly, householders were interviewed regarding their WTP to ensure the provision of a welfare gain. Both per-annum and per-visit payment formats were tested here. Values from such an exercise should, in theory, estimate the compensating surplus measure of welfare gain. Secondly, farmers were asked to state the amount they were WTA (per annum) in compensation for forgoing existing agricultural production in favour of open-access recreational woodland. This latter exercise provides, in theory, measures of the compensating surplus measure of welfare loss. Before discussion of the relative validity of these various analyses, we present a simple comparison based upon the aggregate WTP and WTA sums implied by these results.

ii. Aggregate values

Aggregation of the household WTP measures

Householders were asked to state WTP for a 100 acre block of recreational woodland. The annual format question elicited a simple mean WTP (including those who refused to pay as zeros) of £9.94 per household. The town of Wantage has an adult population of 11,495, so, even if we take an extreme upper bound estimate on household size (so as to derive a lower bound estimate on household WTP) of 2.57 (CSO,1991)[63] this would imply some 4,473 households in Wantage which would in turn imply an aggregate WTP of £44,450 per annum for the woodland.

Turning to consider our per-visit measure of WTP, we elicited a WTP of £0.82 per adult visit (again including those who refused to pay as zeros). The mean estimated number of visits (including those who would not visit) was just under 15 per annum implying a total annual entrance fee expenditure of £12.29 per adult. Grossing up across all adults[64] implies a total annual WTP entrance fees of £141,252.

[63]This figure refers to average UK household size rather than the average number of adults per household. If the latter were used this would increase our estimate of houschold WTP, i.e. we have chosen a conservative, lower bound assumption.

[64]Note that we have already accounted for non-visitors in the annual per-adult visit rate.

Aggregation of the farmers WTA compensation measure

The farm survey estimated a mean WTA compensation of £250/acre p.a. Given that our household survey scenario elicited WTP for a 100 acre site, our estimated WTA for such a site is £25,000 per annum.

Comparison of WTP and WTA measures

Either measure of WTP exceeds our estimate of WTA to a considerable degree. In the case of our annual format we have a simple[65] benefit/cost ratio of 1.78 whilst the entrance fee format yields a ratio of 5.65.

Such results point strongly in favour of the setting-up of such schemes. However, we prefer to retain a cautious approach to the WTP sums. Another way of examining these is to consider the minimum number of payments needed to meet the required aggregate compensation level. Using the per-annum format and our above estimate of household size implies that some 2,515 households (i.e. 56% of all those in Wantage) would need to pay the £9.94 mean WTP for the scheme to break even. Alternatively all households in Wantage would have to pay £5.59 pa for the scheme to again break even. Using the per-visit mean implies that 30,487 individual visits per annum would be required to pay for the forest, i.e. each individual in Wantage would need to make 2.65 paying visits per annum for the site to break even.

iii. Discussion

At first glance this study appears to have been a success and seems to hold out the possibility of the wider application of CV studies to relatively small-scale decision making problems. However, the discrepancy and particularly the relationship between household annual and per-visit WTP is somewhat disturbing. Our discussion of bid curves for these measures suggested that answers to the per-visit format questions represented not true WTP valuations, but rather a "price" influenced by social norm expectations of what respondents felt was reasonable to pay for a forest visit. Conversely we argued that answers to the annual format question were, at least in some way, related to respondents true valuations. How then can "aggregate price" exceed "aggregate value"?

[65]The term 'simple' refers here to the fact that this study represents only a partial cost-benefit analysis of such a scheme.

One explanation of this discrepancy arises from noting that we have reason to believe both that our annual format WTP measure may be downwardly biased by elicitation effects and that our per-visit measure may be upwardly biased by a number of factors. Regarding the annual format measure, our elicitation effect studies (Bateman et al., 1993) indicate that an open-ended (OE) WTP question format (as used in all the Wantage experiments) will produce an estimated mean WTP significantly below that elicited from a dichotomous choice approach[66]. Whilst we stress that the dichotomous choice format need not, *per se*, be producing an estimate of 'true' WTP[67], the conclusion of this work was that OE formats produce, at best, lower bound estimates of WTP. We have compounded this in our calculation of 'aggregate value' by adopting further lower bound assumptions regarding household size. In short 'true' WTP could lie some way above our per-annum estimate.

Turning to the 'aggregate price' derived from our per-visit measure, a number of points should be noted. Firstly, our aggregation assumptions regarding household composition are not as aggressively lower-bound as for our 'aggregate value' estimate. Secondly, we have some reservations regarding estimated visit rate and note that the adoption of the 5% trimmed mean for this variable would result in a 22% fall in 'aggregate price'. More severe reductions in mean visit rate (which averages across the entire study population) are quite feasible resulting in corresponding further reductions in our "aggregate price" estimate. Thirdly, as we have discussed elsewhere (see chapter 3), it is probable that in answering this question respondents are searching for a social norm response regarding a socially appropriate entrance fee. Considerations in forming such a response are likely to include experience of other entrance fees which, as responses to questions regarding other recreation destinations show, includes many with significant fees. Fourthly, the rounding effect commented upon earlier has a far greater relative impact upon answers to the per-visit question than the annual payment question. Thus, for example, many respondents said that they would pay "one pound" per visit. Multiplying through by predicted visits this rounding often leads to an estimate of annual entrance fee payments being above that given in response to the annual WTP question. Finally, as an extension to this, it may be that the spreading of payments via an entrance fee is relatively attractive when compared to the lump sum payment inherent in

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[66]See previous discussion of elicitation effects.

[67]Such a strong conclusion is implied by Arrow et al. (1993) in their preference for dichotomous choice over open-ended approaches.

the annual format question.

In conclusion, the disparity between 'aggregate value' and 'aggregate price' may not be a problem although the above discussion does highlight the need to consider these measures as point estimates within a wide confidence interval.

Turning to consider farmers' WTA responses, the most striking feature of this analysis is the comparatively very high explanatory power of the WTA bid function. This result contradicts findings from many previous WTA studies[68], where respondents have exhibited great difficulty in answering such questions. We believe that our result reflects the fact that UK farmers are well accustomed to making decisions regarding schemes and products which entail differing levels of compensation. These decisions are made with respect to the opportunity cost of forgone alternatives, a factor very well reflected in our bid function. Other WTA studies have interviewed individuals who have no experience of compensation decisions and consequently exhibit extreme uncertainty in answering WTA questions.

Finally, even taking into consideration the various actual and potential problems with this study, the clear excess of households' aggregate WTP (by whatever measure) over the WTA compensation amounts stated by farmers does indicate that the implementation of such a scheme as that hypothesised in the questionnaire scenario may well result in the generation of a significant net social benefit[69].

4.3.3: THETFORD 2 CV/TC STUDY

Between 26th March and 25th April, 1993, 351 parties of visitors to Lynford Stag, Thetford Forest, were interviewed in an on-site survey. Data was collected for both a CV and ITC study[70] with the latter eliciting sufficient data to employ GIS route analysis of travel distance and travel time[71]. Many of the findings from our earlier studies influenced the design of these experiments which, we feel, allow for a significantly improved and more sophisticated degree of analysis.

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[68]See review in Mitchell and Carson (1989).

[69]A more certain statement concerning the total net benefits of such a scheme can be made if we assume that farmers have incorporated direct afforestation costs into their WTA compensation statements. This is feasible and, given the fact that grants in respect of many of these costs are available, such an assumption does not appear too strong.

[70]Further details of these studies and the joint survey questionnaire are given in appendix 2.

[71]This data was also used to estimate an 'arrivals function' (detailed in chapter 5) which combines information from the survey with details regarding population distribution and road network availability and quality to predict the number of visitors to other specified sites.

The Lynford Stag site was chosen primarily for the transferability of its recreational attributes. While there are a few other minor attractions,[72] the main activity of the site is open-access, recreational walking. This means that many of the attribute related measures of our analysis may be transferable to other sites.

4.3.3.1: Thetford 2: The CV study[73]

i. Study focii

In coming to this study we felt that our previous work, together with our benefit transfer analysis of reviewed studies, had provided us with a good grasp of the range of valuations being derived from a typical CV study of UK woodland recreation. What we wished to investigate here was the extent to which theoretically reasonable re-specifications of CV questionnaire design impacted upon WTP response. In particular we wished to address two issues:

(i) The mental accounts question: In chapter 2 we discussed the extent to which individuals do, or do not, consider other demands upon disposable income when answering WTP questions.

(ii) Payment scenario effects: In the Thetford 1 study separate groups were presented with either per annum or per visit payment scenarios. The Wantage experiment presented first the per annum and then the per visit scenario to all respondents. In the Thetford 2 CV study we set out to see whether answers to these questions were to some extent endogenous to the instrument design. Specifically we wanted to investigate the possibility of an ordering effect, i.e. does the answer to one question depend upon prior responses? If so, to what extent can the inclusion, exclusion or re-ordering of questions affect responses?

These two potentially additive or interactive effects were investigated through a split-sample study design in which respondents were divided into two groups each of which was further divided into two subgroups as follows:

[72]The site also has a car park, an information board giving details of walks at the site, a few picnic benches and barbecue sites, a child's swing and wooden climbing frame, and some toilets. However, our survey confirms that by far the major activity is recreational walking.

[73]This study will be published as Bateman and Langford (forthcoming b).

Group B: Prior to any WTP question, respondents were asked to calculate and state their annual recreational budget.

Group NB: No budget question asked prior to any WTP response.

Subgroup 1: WTP per annum (tax) asked prior to WTP per visit (fee) question.

Subgroup 2: WTP per visit (fee) asked prior to WTP per annum (tax) question.

We therefore have four subgroups each of which provides both a tax (per annum) and a fee (per visit) WTP response.

Following the findings of our previous research, an open-ended elicitation method was used throughout as a conservative approach to deriving WTP responses. In addition to the WTP questions the survey also elicited information regarding all relevant visit, socioeconomic and interview condition variables necessary for subsequent validity analysis.

ii. The payment principle question

Prior to the WTP (and budget) questions, respondents were asked whether or not they were willing to pay anything at all. This 'payment principle' question was included because we felt that interviewees who did not wish to pay might feel inhibited from stating such a response if they were directly asked how much they were willing to pay. In such a case we felt that some of these respondents might state some non-zero sum because they felt embarrassed, or otherwise inhibited about admitting their true, zero, willingness to pay.

73% of respondents stated that they were prepared to pay at least some amount for the recreational facilities provided at Thetford Forest. This is somewhat lower than for our study of the Norfolk Broads (85% acceptance) and may reflect the increased number of sites which might substitute for Thetford compared to the almost unique nature of Broadland.

The determinants of the decision to respond positively to the payment principle question were investigated through chi-square analysis. This indicated weak (statistically just insignificant) positive relationships with income, travel distance and visit duration,[74] and a similarly weak negative relation with interest in wargaming and other structured recreational pursuits. Significant and positive relationships were found for three activity groups: those who often take short walks of less than two miles at the site ($\chi^2 = 6.52$)[75]; those who often

[74]All factors which support the findings of our Thetford 1 study.
[75]Critical χ^2 values with 1df = 3.84 ($\alpha = 5\%$); = 6.64 ($\alpha = 1\%$).

use the site for relaxation/enjoying scenery ($\chi^2 = 11.95$); and those who sometimes or often enjoy nature watching at the site ($\chi^2 = 8.13$). These factors are clearly interrelated and further analysis confirmed that the majority of those who stated that they often relaxed and enjoyed the scenery at the site also stated that they sometimes or often enjoyed nature watching and went for short walks. Clearly then such factors could not be entered separately within a logit model of payment principle responses (as used in Bateman *et al.*, 1992). Consequently an amalgam variable was created whose significance was maximised by grouping together all those who exhibited at least two of these three factors. The resultant variable (which we label as VISITOR A) proved to be highly significant both in explaining responses to the payment principle question ($\chi^2 = 16.54$) and in subsequent bid curve analysis.

Reasons for both positive and negative responses to the payment principle question were explicitly investigated via direct questioning of respondents. Those who refused to pay anything at all were presented with a show-card detailing various set responses regarding reasons for refusal[76] and asked to state which category response best described their reason for refusal. Table 4.15 details results from this analysis.

Table 4.15: Respondents stated reason for refusing the principle of payment

No.	Reason for refusal[1]	No. of respondents	% of all refusals	% of total sample[2]
1	Cannot afford to pay	2	2.1	0.6
2	Does not like site	0	0.0	0.0
3	Prefers natural state	10	10.4	2.8
4	Refuses to value site	11	11.5	3.1
5	Someone else should pay	6	6.3	1.7
6	Pays too much tax already	24	25.0	6.8
7	Rejects entrance fees	7	7.3	2.0
8	Other	12	12.5	3.4
9	Not stated	24	25.0	6.8
	Totals	96	100.0	27.3

Notes: 1. Full details, show cards and questionnaire reproduced in appendix 2
2. Total sample size = 351
Numbers rounded to one decimal place.

[76]Show card and categories were based on our prior woodland studies.

Considering the reasons given for refusing to pay for the site we can see that the major specified issue is one of economic constraint (inability to pay, reasons 1; and current expenditure demands, reason 6) although in some ways this might reflect a rejection of the tax and fee vehicles (reasons 6 and 7). Reason 5 (someone else, such as the government, should pay) is the extreme free-rider response. The small number of individuals in this category is encouraging but may nevertheless point to a larger group of respondents who, while prepared to pay something, still understate their total WTP. Our Norfolk Broads study (Bateman et al., 1993) indicated that OE elicitation methods may suffer from a certain degree of understatement. This may apply here although the relatively low numbers in refusal category 5 suggest that this may not be too much of a problem in this instance and will in any case result in conservative predictions of total WTP.

The one category which would suggest that our study is fundamentally invalid is that for individuals who refuse to value the site (response 4). Reasons for such a response may be diverse. However, even if we assumed that all such respondents fundamentally rejected the principle of monetary evaluation, the small number of individuals in this category suggests that we do not have a problem here.

Respondents who accepted the principle of paying at least some amount were similarly asked their reasons for so doing. Table 4.16 details results from this analysis.

Table 4.16: Respondents stated reason for accepting the principle of payment

No.	Reason for acceptance[1]	No. of respondents	% of all acceptances	% of total sample[2]
1	Reasonable amount to pay	28	11.0	8.0
2	Similar price to equivalent sites	8	3.1	2.3
3	Lives close to site	8	3.1	2.3
4	Visits site often	5	2.0	1.4
5	Keen on countryside	28	11.0	8.0
6	Keen on forests	3	1.2	0.9
7	Keen on wildlife/environment	25	9.8	7.1
8	Preserve for future	92	36.1	26.2
9	Other	3	1.2	0.9
10	Not stated	55	21.6	15.7
	Totals	255	100.0	72.7

Notes: 1. Full details in show cards reproduced with questionnaire in appendix 2.
2. Total sample size = 351
Numbers rounded to one decimal place.

Interpretation of some of the responses in table 4.16 must be somewhat loose as several categories are overlapping (e.g. 5, 6 and 7). However, the lack of respondents in category 2 is encouraging[77]. Perhaps the most interesting observation is the large number of respondents stating that their prime motivation in agreeing to pay something was to preserve such areas for future generations. The wording of this category was phrased so as to separate this from option value, although it is always possible that some respondents may have been influenced by such considerations. Nevertheless the prime rationale behind such a response would appear to be bequest value. In other papers we have been somewhat suspicious of such statements of altruism in CV studies (Bateman, 1992). However, the strength of such apparent feeling within this sample is remarkable and raises an interesting question regarding how the respondent views his or her own WTP bid. While it seems probable that per-visit WTP (entrance fee) bids would relate to the pure use value of a visit, the results of table 4.16 suggest that for many people, responses to per annum WTP (tax) questions are quite likely to be a mixture of use plus non-use (bequest and existence) value. In a fully informed, rational expectations model of respondent behaviour we would therefore be able to use the difference between the annual equivalent of per visit response and stated per annum WTP as equal to non-use value. Unfortunately we suspect that problems regarding the discounting of future expectations, measurement error within the individual and (probably most important) payment vehicle effects, may confound such a calculation. Nevertheless the strength of opinion expressed in table 4.16 (and the desirability of successful estimation of non-use values) suggests that this is a worthwhile avenue for future research.

iii. <u>Mean WTP and confidence intervals</u>

At the start of each interview, respondents (unbeknown to themselves) were randomly allocated to one of the four subgroups described above such that roughly one-quarter of the total sample was in each subgroup. However, these numbers were then randomly disturbed by those respondents who stated that they were not willing to pay anything at all. As the payment principle question preceded any WTP question, the consequent reduction in subsample sizes is random and does not invalidate or in any way contaminate WTP responses. However, it does mean that we need to subsequently adjust for the differing subsample sizes

[77]Particularly as this appears so near the top of the show card list of options, i.e. it might be inflated by any list-bias effect (Oppenheim, 1966).

when calculating mean WTP by redistributing these zero bids equally amongst all subgroups[78]. In the following subsections we present results from the analysis of, firstly, per annum and, secondly, per visit WTP responses.

a) Per annum (tax) WTP responses

Table 4.17 details mean WTP per annum (via taxes) and 95% confidence intervals (in brackets) for each of our four subsamples.

Table 4.17: Mean WTP (tax) per annum (£) and 95% confidence intervals (in brackets) for each subgroup (including payment principle refusals as zeros)

Budget question	Payment ordering scenario	
	1 (tax then fee)	2 (fee then tax)
NB (not asked)	12.55 (8.11 - 16.99)	7.62 (2.87 - 12.37)
B (asked)	32.60 (21.76 - 43.43)	16.37 (11.19 - 21.55)

Consideration of the results of table 4.17 indicates that the inclusion or exclusion of the recreational budget question, and/or changes in the ordering of payment vehicle presentation, results in consistent and major impacts upon stated WTP[79]. The inclusion of the budget question raised mean annual WTP (tax) by a factor of 2.60 for vehicle ordering scenario 1 (tax then fee) and by a factor of 2.15 for vehicle ordering scenario 2 (fee then tax). Given the magnitude of change this clearly raises major questions for CV research. The direction of change is also interesting. Most commentators (Mitchell and Carson, 1989; Willis and Garrod, 1993) discuss cases in which, *a priori*, we would expect that respondents' consideration of annual expenditure upon recreation and consequent budget constraints would lead to a reduction in stated WTP compared to statements made without such consideration. However, here we observe a very strong opposite effect whereby respondents who are asked to calculate their present annual expenditure state significantly higher WTP sums than those

[78]Further details in appendix 2.

[79]Note that there is some overlap of confidence intervals for changes between certain subgroups (although not for others). Nevertheless strong impacts do appear to have been detected here. In every case the mean from one subgroup falls outside the confidence interval of its vertical or horizontal neighbour (i.e. where we vary just one factor; as the factors have contrary effects, varying both tends to cancel each other out).

not asked the prior budget question.

Why has this effect occurred? It seems to us that two interpretations are possible, one deriving from economic theory and the other influenced by psychological literature. An economic argument might be that respondents forced to overtly consider their annual recreational budget find that, on average, this accounts for a significant portion of their total annual expenditure, perhaps more than they realised without such consideration. Certainly stated recreational budgets were not insignificant. The mean budget (£227.30) was considerably affected by the skewed nature of this distribution as described (with income) in table 4.18. Nevertheless, the median value of £120 shows that most respondents had considerable recreational budgets. Following this line of argument, upon consideration of the apparent importance of recreation in individuals' preference sets, such respondents gave higher WTP sums than would otherwise have been stated.

Table 4.18: Descriptive statistics for respondents' annual recreational budget and gross household income (£ pa)

Variable	No. asked question	No answering question	mean	median	trimmed mean	st. dev.	Q1	Q3	max.	95% CI lower	95% CI upper
Budget	167	152	227.30	120.00	169.40	345.50	70.00	250.00	2500.00	171.90	282.60
Income	351	348	18,247	17,500	17,524	10,823	12,500	25,000	55,000	17,106	19.388

If we accept the economic argument then a supplementary question arises as to which WTP measure (with, or without, the prior budget question) is correct. This line of reasoning would seem to suggest that answers formulated following the consideration of available budgets will be less susceptible to mental accounting problems and therefore preferable.[80] However, this conclusion runs counter to that provided by psychological interpretations of our results. Here the calculation of the annual budget (which is relatively high compared to WTP for the forest) acts as an anchor for subsequent WTP statements. Kahneman et al. (1982) suggest that such an effect is most likely to occur where individuals are inexperienced and face considerable uncertainty in forming their response. Certainly individuals do not have much experience of setting prices as opposed to reacting to them[81].

[80]Such a conclusion would imply that the bulk of the CV literature, which has not incorporated mental account questions, is flawed.

[81]Our own work (Bateman et al., 1993) suggests that respondents exhibit greater uncertainty in answering OE (as per this experiment) than DC WTP questions. Use of an OE format may therefore exacerbate this problem although the extent of this exacerbation should be reasonably constant across respondents ie. elicitation effects do not explain these findings. In future work we would aim to repeat this experiment within a DC format to reduce the level of uncertainty which OE formats may induce.

Clearly this finding gives us pause for thought regarding the degree to which WTP responses may be manipulated by small and apparently defensible changes in questionnaire design. The responsiveness of stated WTP to the inclusion of the budget question is remarkable and a matter of significant concern for future CV studies.

Turning to consider the impact of changing the order of payment questions upon per annum responses: for those subgroups not given the prior budget question, asking for per visit WTP before the per annum question lowered the latter to just 60.7% of stated annual WTP when not preceded by a per visit question. For those subgroups who were given a prior budget question, this disparity increased so that annual WTP preceded by a per visit question is just 50.2% of annual WTP not so preceded. Here an economic justification might be that such respondents were taking prior per-visit payments and extrapolating them to produce a per-annum sum[82]. However, this would imply that per annum bids made prior to per-visit bids were in error. Here then the psychological argument that the relatively small per-visit WTP sums have anchored subsequent per annum statements, seems the most logical explanation of these results[83].

Consideration of the rates of impact of the mental account (budget) and ordering (payment vehicle) effects suggests some interaction. It appears that the use of a per visit question prior to the WTP per annum response diminishes the impact upon WTPpa of inserting the budget question. This is to be expected as inclusion of the per-visit question restricts the range of per annum responses. Furthermore inclusion of a prior budget question increases the disparity between an otherwise unpreceded WTPpa bid and the response to the same question when preceded by a per visit question. Here the inclusion of the budget question opens up the range of subsequent per annum WTP responses.

b) Per visit (fee) WTP responses

The mental account and payment vehicle ordering effects upon per visit WTP bids were also analysed. Table 4.19 details mean WTP via per visit fees for each subgroup and 95% confidence intervals. Here, as before, all payment principle refusals are included as zeros allocated equally between subgroups.

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[82]Factors such as discounting, uncertainty and risk mean that we would not expect a simple relationship between per visit and per annum WTP.

[83]Which in turn can only enhance the anchoring interpretation of the budget effect.

Table 4.19: Mean per visit (fee) WTP (£) and 95% confidence intervals (in brackets) for each subgroup (including payment principle refusals as zeros)

Budget question	Payment ordering scenario 1 (tax then fee)	 2 (fee then tax)
NB (not asked)	0.45 (0.35 - 0.55)	0.20 (0.11 - 0.29)
B (asked)	0.78 (0.53 - 1.03)	0.46 (0.30 - 0.62)

Considering table 4.19 we can see that the design effects detected in the per annum experiments have been repeated in the per-visit studies, although because fee responses were smaller than per annum bids, the line of ordering effects is reversed. Here the prefixing of per visit WTP questions by per annum questions increases per-visit WTP bids. Similarly, and as before, the inclusion of a prior question regarding recreation budgets leads to significant increases in subsequent per visit WTP responses. The economic and psychological arguments surrounding these effects are as before although we feel that the influence of 'social norm' pressures upon per visit responses (see chapter 3) may have diminished the intensity of these effects compared to those observed in the per-annum experiments. This additional factor is most clearly demonstrated when we contrast the per-visit means in table 4.19 with their per annum equivalents in table 4.17. In both cases the lower left hand cell represents WTP when both positive (budget and ordering) effects are in operation resulting in the most extreme WTP responses. In the per-annum experiments the positive budget effect (vertical shift to this cell) raises mean WTP by a factor of 2.6 while the positive ordering effect (horizontal shift to this cell) increases mean WTP by a factor of 2.0. In the per visit experiments the equivalent factor increases are in both cases roughly 1.7. We would argue that this relative diminishment of extreme effects by the per-visit vehicle are due to the 'social norm' pressures exerted upon respondents who take into account notions of a socially 'fair' entrance price (and/or experience of fees elsewhere) when formulating their per-visit WTP response.

iv. Validation: bid function analysis

Validation of our results was carried out as for previous studies with the main emphasis being upon statistical investigation of the factors determining WTP responses.

a) Per-annum WTP responses

Examination of the most appropriate functional form was conducted as before and again concluded that a natural log specification of the dependent variable fitted the data best. Following this, consideration switched to identification of significant explanatory variables via one-way analyses of variance and stepwise linear regression. The one-way analyses of variance highlighted a number of interesting relationships. Weakly significant (α >0.05) factors included a negative relation between WTP and being a first time visitor or member of a sports/WI or other club and a positive relation with the number of day visits to the site annually[84]. Strongly significant (α <0.05) variables were as follows (figures in brackets are p values from one-way analyses of variance):

$ORDER_{tax}$	=	1 if respondent had been asked a per-visit (fee) question prior to per annum (tax) WTP; = 0 otherwise (p = 0.000)
BUDGET	=	1 if respondent had been asked to state annual recreational budget prior to per annum (tax) WTP; = 0 otherwise (p = 0.000)
NOTCAR	=	1 if visitor did not arrive by car; = 0 otherwise (ρ = 0.003)
SUPERB	=	1 if respondent rated scenery at the site as superb; = 0 otherwise (p = 0.028)
RSPB	=	1 if respondent was a member of the Royal Society for the Protection of Birds; = 0 otherwise (p = 0.021)
TRUST	=	1 if respondent was a member of a wildlife trust; = 0 otherwise (p = 0.040)
LOWINCOME	=	1 if respondent's household income was below £5,000 per annum; = 0 otherwise (p = 0.048)

All these explanatory variables had significantly positive effects upon per-annum WTP with the exception of the $ORDER_{tax}$ and LOWINCOME variables which were negatively related. Table 4.20 details the best fitting regression model of per annum WTP. A GLM analysis was used to test an interaction term between the $ORDER_{tax}$ and BUDGET variables. However, this was found not to be significant (p = 0.375).

[84]Other even weaker but correctly signed factors include: income(+ve); sunniness(+ve); temperature(+ve); multi-site trips(-ve); enjoyment of the journey(-ve); length of time on site(+ve); and whether respondent was a tax-payer(+ve).

Table 4.20: Best fitting bid function for per annum WTP.
Dependent variable = natural log of per annum WTP (ln WTPpa)

variable	coeff.	st. dev.	t-ratio	p
Constant	1.2573	0.1157	10.86	0.000
$ORDER_{tax}$	-0.6024	0.1359	-4.43	0.000
BUDGET	1.4668	0.1370	10.71	0.000
NOTCAR	1.1772	0.3259	3.61	0.000
SUPERB	0.6226	0.2033	3.06	0.002

s = 1.267 R^2 = 31.8% R^2(adj) = 31.0%
Regression F = 40.18 p = 0.000
Variables as defined in text. Tests confirmed no multicollinearity problems.

The overall predictive power of our best fit model is, by CV standards, quite good for an OE study. What is of concern is the confirmation of the strength of the vehicle ordering and mental accounting effects upon individuals' responses. The inclusion of a prior budget question very significantly increases subsequent per-annum WTP responses whereas a prior per-visit WTP question acts to reduce subsequent per-annum responses. Of the two the budget effect is the greater both in terms of absolute magnitude and statistical significance, but both factors are very clearly at work here.

b) Per visit WTP responses

As before validity testing focussed upon estimation of a bid function for WTP responses. Initial investigations showed that, due to a relative lack of variation in per-visit WTP responses, a linear dependent variable fitted the data better than a log-linear specification. We interpret this as a sign that responses to per-visit questions are dominated by our 'social-norm' factors rather than by standard socioeconomic and visit characteristics.

Simple data analysis techniques were used to identify potential explanatory variables[85]. A number of interesting but statistically weak quadratic relationships with WTP were noted. Per visit WTP was found to initially rise with distance (particularly noticeable at about 15 miles). The reason for this would appear to be linked to the purposefulness of the visit. Visitors who travel some considerable way specifically to visit the site clearly have a strong preference for its attractions. However, as distance becomes particularly long, purposefulness falls and visits become more by chance than design, i.e. such very long

[85]Techniques include histograms and plots, calculation of correlation coefficients and one-way analyses of variance.

distance visitors generally happen upon the site by accident and stop just to break the journey, their real destination being elsewhere. This interpretation is supported by the positive relation of WTP to visitors' rating of Thetford in terms of their overall day's enjoyment and negative relationships with enjoyment of travel and visits to other sites that day. These findings underscore the importance of using enjoyment-adjusted travel costs in our subsequent TC study of the site, without which we would overestimate consumers surplus for the site.

A second quadratic relationship was found with the number of day visits per annum. Here WTP is initially relatively small at low numbers of annual visits. This is a function both of the meanderers and passers-by referred to above, and because those who make few trips may do so because they have many available alternatives. As the number of trips increases so, initially, does per-visit WTP. Here we have respondents who like the site but do not make very high numbers of visits because of trip distance and substitute availability (which will be collinear). However, at very high numbers of visits, WTP per visit falls back again. Such respondents probably live close to the site and may have few available substitutes. For them a per-visit fee would translate to a considerable annual cost to which they are understandably resistant. Such observations are reflected in annual WTP sums which rise with visitation rates but at an eventually declining rate.

A third quadratic, identified to some degree in all our empirical studies, is with age. Both the young and old tend to give lower WTP bids (both per-annum and per-visit) than the middle-aged, a result most likely to be reflecting income distributions.

A number of simple but statistically weak linear relationships were also identified. WTP per visit was found to be negatively related to having started the day's journey at home rather than from a holiday address, and to the principle activities of wargaming (not catered for at the survey site) and dogwalking (for reasons given above; dogwalkers tend to live locally and visit often). Weak positive relations were found with picnicking and relaxing/enjoying scenery as principle visit objectives, and with income.

A number of statistically significant (α <0.05) variables were identified as follows (numbers in brackets are p values from one-way analyses of variance):

$ORDER_{fee}$	=	1 if respondent had been asked a per-annum (tax) question prior to per-visit (fee) WTP; =0 otherwise (p = 0.033)
BUDGET	=	1 if respondent had been asked to state annual recreational budget prior to per-visit (fee) WTP; =0 otherwise (p = 0.024)
CAMPOFT	=	1 if respondent often camps in the area; = 0 otherwise (p = 0.007)

SUPERB	=	1 if respondent rated scenery at the site as superb; = 0 otherwise ($p = 0.014$)
STAY4	=	1 if respondent spends at least 4 hours on site per visit ($p = 0.035$)
BUSINESS	=	1 if respondent stated that the prime reason for visiting the site was connected to a business meeting;[86] = 0 otherwise ($p = 0.000$)
GREEN	=	1 if respondent is a member of at least one of the following: any wildlife trust, the National Trust, the Broads Society, Friends of the Earth, Greenpeace; = 0 otherwise ($p = 0.004$)

Unlike the per-annum experiment, the ordering variable ($ORDER_{fee}$) is now positively related to stated (per-visit) WTP, indicating that the asking of a prior per-annum question raised respondents subsequent per-visit WTP bid. The relationship of WTP with BUDGET is (as before) positive, as is that with CAMPOFT, SUPERB, STAY4 and BUSINESS. This is all as expected. However, against our first expectations, the variable GREEN proved to be strongly negatively related to per-visit (fee) WTP although membership of such groups was positively related to annual WTP[87]. It seems that the members of such groups strongly object to the ending of the open-access nature of the site implicit in the fee vehicle. It is interesting to note that the survey took place in the middle of a well publicised, year-long review of the Forestry Commission which had raised fears of the wholesale privatisation of the estate and consequent loss of current open-access rights. This strong objection to fees by such respondents (who were the most likely to be aware of this review[88]) may well reflect a deeper protest against the prospect of privatisation[89].

All the variables listed above are simple, two-level, dummies. The number of respondents at any level was 45 or above in all cases except for the variable BUSINESS

[86]This information was elicited from interviewees' comments when specifying the 'other' category in answer to a question regarding the main reason for coming to the forest.

[87]Interestingly membership of non-environmental groups such as sports clubs was (weakly) positively related to per-visit WTP and negatively related to per-annum WTP. This makes sense as such respondents visit forest sites relatively less and therefore would minimise expenditure on such recreation by paying per use rather than via a flat annual rate.

[88]Most of these groups, including even the normally sedate National Trust, had lobbied hard against the possibility of privatisation (see Stirling, 1994).

[89]Such protests do, arguably, cause problems for the validity of our per-visit valuations. However, this is to some extent examined in our consideration of answers to the payment principle question. Furthermore, the theoretical problems raised by ordering and mental accounting effects are of a greater magnitude.

which had the value 1 for just two interviewees but proved to be highly significant.

Table 4.21 reports the best fitting bid function[90] which included both of our focus variables ($ORDER_{fee}$ and BUDGET) and any other significant ($\alpha < 0.05$) explanatory variables.

Table 4.21: Bid function for per-visit WTP responses

Explanatory variable	coeff.	st. dev.	t-ratio	p
Constant	0.4647	0.0617	7.53	0.000
BUDGET	0.0865	0.0685	1.26	0.207
$ORDER_{fee}$	0.1224	0.0679	1.80	0.072
GREEN	-0.2198	0.0767	-2.87	0.004
CAMPOFT	0.3175	0.0984	3.23	0.001
BUSINESS	5.1676	0.4505	11.47	0.000[1]

s = 0.6281 R^2 = 33.4% R^2 (adj) = 32.4%
Regression F = 34.42 (p = 0.000)
Note: 1. As noted in Table 3.14, the p-value reported here are those produced by default by the statistics package. In this instance the small number (2) of observations on the BUSINESS variable means that the sample df is somewhat unrepresentative. Using df = 2 reduces the p-value slightly to 0.005.

Table 4.21 reveals several interesting characteristics of the per-visit WTP responses. The focus variables $ORDER_{fee}$ and BUDGET, while exerting pressure upon bids, are not the highly significant determinants exhibited in per-annum responses. Indeed neither satisfy a 5% significance test. Other explanatory variables are as expected (given our previous discussions). With the exception of the BUSINESS variable (which only applies to two responses), by far the strongest determining factor is the constant. We believe that this, combined with the good overall degree of fit (for an OE CV bid function), gives strong support to our argument that per-visit responses are highly determined by individuals' common conception of a 'social-norm' level of acceptable charging for entry to such a site. Respondents are, we argue, tempering their own true valuations with both their experience of fee paying (e.g. through car-parking fees at comparable sites) and their conceptions of a socially just level of payment for what is, traditionally, an open-access good.

[90]Two unusual observations were omitted from this regression. For details see appendix 2.

v. The Thetford 2 CV study: conclusions

This study has raised as many questions as it has provided answers. By analysing the extent to which WTP bids can be manipulated by design variations we have raised questions as to which design permutation is preferable. The variations tested are, we feel, all justifiable. The introduction of a prior budget question can be justified on the grounds that this addresses the possibility of mental accounting error and indeed studies have adopted such an approach (Willis and Garrod, 1991; 1993). Furthermore, as several studies have adopted both per-visit and per-annum measures (Bishop, 1992; Whiteman and Sinclair, 1994), the possibility of these interacting in a way controlled by their ordering is worrying. Our study shows that mean per annum WTP can be almost halved by the inclusion of a prior per-visit question or more than doubled by a prior budget question (with the budget effect somewhat outriding the payment ordering effect if both priors are included). The fact that both these effects are less pronounced upon per-visit WTP bids is hardly comforting if this is as a result of (and evidence for) a social-norm conditioning of such answers.

The implications of these findings for our research (and for the wider use of CV) may depend upon the perspective of the individual researcher. We have experienced very differing reactions from colleagues to these findings. Some have taken them as further evidence of the 'sheer subjectivity' of CV results. Conversely others have pointed out that, while results could be doubled or halved they could not be increased or decreased by a larger factor, i.e. the possibility of creating a confidence interval of valuation arises.

We have some sympathy for both interpretations of these findings. Certainly when we take into account the effect upon WTP of varying the elicitation method (Bateman *et al.*, 1993), then the design effects observed in the present study are certain to widen any resultant 'valuation envelope'. In effect, by adopting an OE format for this study, we have ensured a conservative, lower-bound design with respect to elicitation effects. To adopt a further lower-bound assumption with regards to the design effects studied here might be somewhat dangerous, certainly the lowest mean WTP sums of £7.62 per annum and £0.20 per visit do appear highly conservative. This is a thorny problem, beset with uncertainties to which we return later.

4.3.3.2: Thetford 2: The ITC Study[91]

Alongside the CV experiments, the Thetford 2 study undertook a travel cost analysis of visitors recreation use-value for Lynford Stag. Following the discussions of chapter 2 we again used an individual rather than zonal (Clawson-Knetsch) approach to the TC. Here we provide summary of results and discussion of this study. Full results are given in appendix A2.4.2.

Three research objectives were defined for this study:

1. To examine the application of geographical information systems (GIS) to travel cost studies. It was felt that the spatial analysis capabilities of GIS were of considerable potential value to such studies[92].

2. To conduct a full sensitivity analysis across a range of time cost and travel cost assumptions. The valuation of such costs clearly has considerable impact upon subsequent consumer surplus estimates but, as discussed in chapter 2, there is some debate regarding both the absolute value and methodological approach towards valuation of these cost elements.

3. To assess the impact and validity of using ordinary least squares (OLS) or truncated maximum likelihood (ML) estimation techniques. Chapter 2 showed that OLS approaches are technically invalid in that they fail to recognise the truncation of non-visitors. Nevertheless many TC studies have used OLS techniques (see appendix 1 and our own Thetford 1 ITC study) and a comparative investigation appeared timely.

<u>The survey</u>

All 351 parties interviewed in the Thetford 2 CV study were also asked travel cost questions. Therefore sampling details are as before[93]. Several survey questions focused upon the trip itself. Respondents were asked to state:

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[91]Details of this study are published as Bateman et al. (1996b).
[92]Further details regarding the GIS exercise are given in Bateman et al. (1995c).
[93]The common CV/ITC questionnaire used in the Thetford 2 study is reproduced in appendix A2.4.3.

(i) Home address, and trip origin if different to this (e.g. if on holiday away from home);

(ii) How they travelled to the site;

(iii) The perceived travel time and cost;

(iv) The number of other sites visited during the days trip;

(v) The proportion of the whole days enjoyment attributable to time spent travelling; time spent at the survey site; time spent at other sites.

Perceived and GIS calculated travel distance and duration

As stated, a prime objective of this study was to examine the potential application of GIS spatial analysis techniques to the TC. It was decided that a simple test of effectiveness would be to compare respondents' perceptions of travel distance and duration with those calculated through use of the GIS. A-priori it is not immediately clear which of these approaches is superior. If we use visitors' statements then these should reflect individual routing decisions and travel speeds. In particular they will highlight visitors who take routes which are not shortest distance/duration so as to increase enjoyment of the journey. However, a problem with reliance upon interviewees' description of the journey is that both distance and duration estimates are liable to suffer from rounding effects. This is likely to be proportionately worse for shorter journeys where the rounding error may well be relatively large. The GIS approach addresses this problem directly by producing accurate estimates of distance and duration. However, the drawback of this approach is that, unless highly detailed trip itineraries are elicited, assumptions have to be made regarding logical trip routing which may not capture deviations due to those who take unusual routes to a site. Nevertheless, previous studies of UK forest recreation (e.g. Colenutt and Sidaway, 1973) have suggested that variables such as minimum travel time provide highly significant determinants of visit rate. Comparison of ITC results based upon perceived costs with those based upon GIS calculations therefore seemed an interesting exercise.

Calculations of GIS trip costs first required accurate information regarding trip origin. Using the data collected from question (i) above the national grid reference of trip origin was located by consulting the Ordnance Survey Gazetteer of Great Britain (Ordnance Survey, 1987)[94]. Figure 4.8 illustrates trip origins for the entire sample in relation to the survey site. This shows clearly the importance of spatial factors in the determination of visits. Trip origins were concentrated around Thetford, with over 90% of visitors having set out from within 100 miles of the site. However, straight line distance is clearly a rather crude determinant of visits and one of the principle advantages of adopting a GIS approach was that it allowed us to account for both the distribution and quality of the available road network.

Digital road network details were extracted from the Bartholomew 1:250,000 scale database for the UK. This source provides information on the quality and width of roads, distinguishing 15 road categories ranging from minor, single-track country lanes to six-lane motorways. Computing time and space limitations made it impractical to assemble a road network for the entire area covering origins of Thetford visitors (this ranged from Edinburgh in the north to Hampshire in the south). We therefore defined a study area to include the counties of Norfolk, Suffolk and Cambridgeshire, together with adjoining districts in Lincolnshire and Essex[95]. This encompassed over 92% of the visitor origins. Figure 4.9 illustrates the resulting digital road network. Supplemental data for visitors from outside this region was obtained by use of the Automobile Association's 'Auto Route' package[96].

The classification and quality of individual roads is defined in the Bartholomew's database. By applying differential road speeds to these details, travel times can be calculated for discrete sections of road. From these, travel times can be calculated for the whole of the available road network. Data detailing average travel speeds for differing categories of road were obtained from a variety of sources[97]. The road speed estimates derived from this exercise are detailed in table 4.22.

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[94]Like all our data from all surveys, the recording accuracy of this data was checked by double-punching all completed questionnaires and comparing resultant datasets.

[95]The Bartholomew's road coverage is stored in map tiles (100 km squares) on the national grid. The relevant map tiles were appended and subsequently clipped using the study area boundary as defined above. Undershoots (common in the Bartholomew's data) were located and corrected whenever possible. Further details in Bateman et al. (1995c).

[96]Because of the rather general digital road network used by Auto Route, this package was not suitable for analysing micro-routing decisions such as those taken by the majority of respondents who have trip origins relatively near the site.

[97]Sources include DoT (1992, 1993); Gattrell and Naumann (1992); the Automobile Association's 'Autoroute' software; and the authors knowledge of routes in the study area. Further details are given in appendix A2.42 and Bateman et al. (1995c).

Figure 4.8: Trip origin for visitor sample: Lynford Stag, Thetford Forest

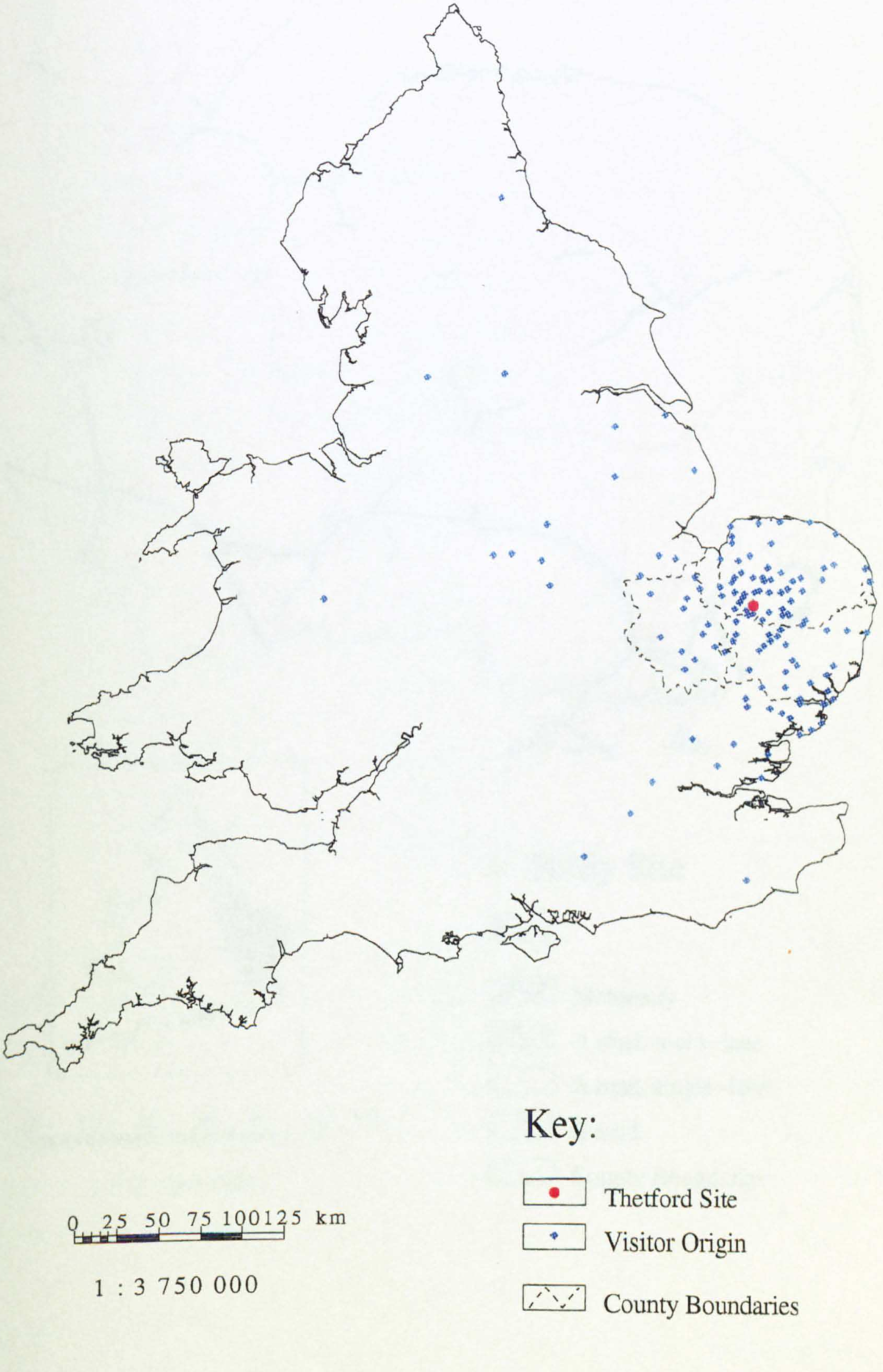


Figure 4.9: Digital road network for the Thetford 2 ITC study

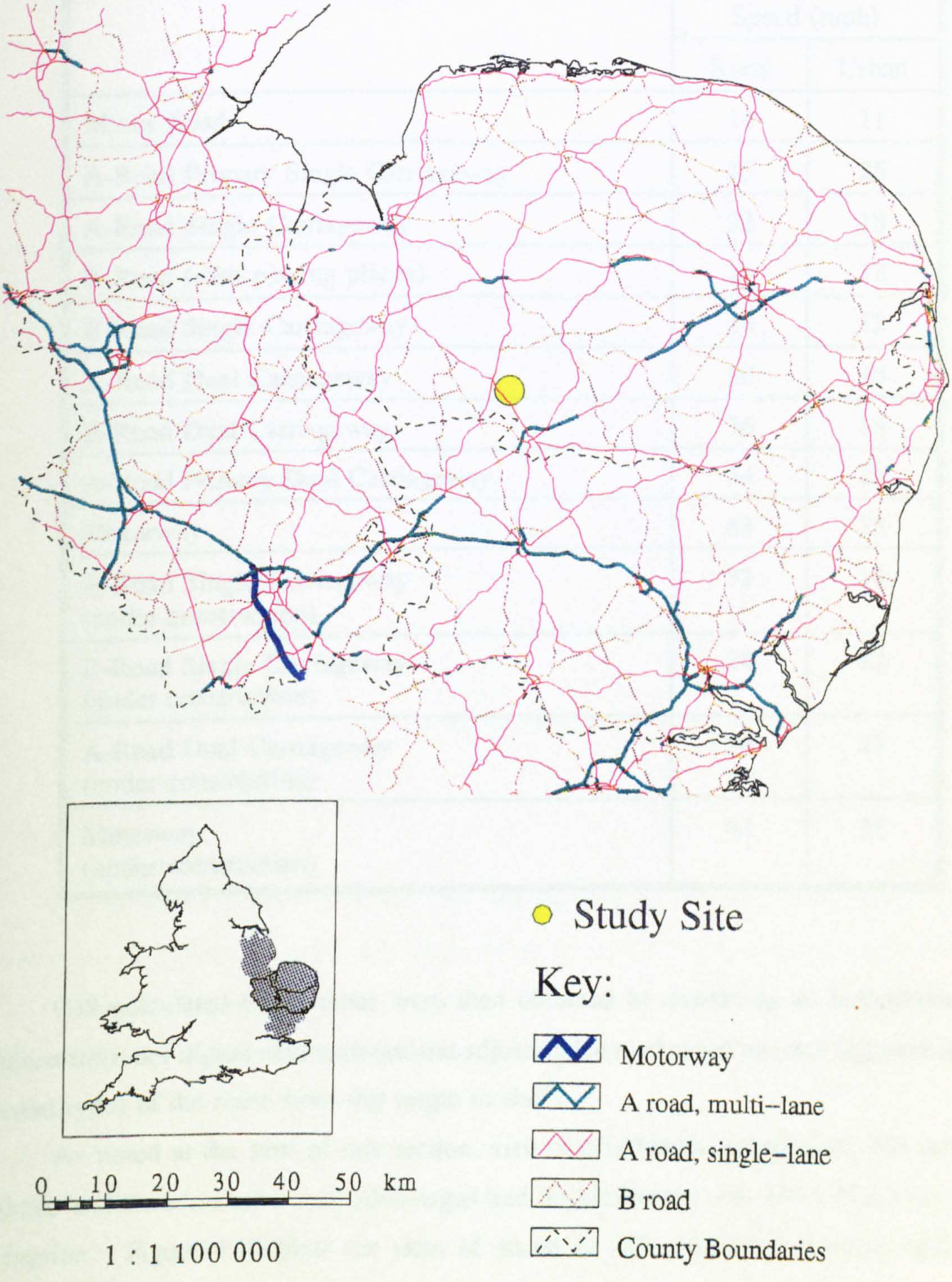


Table 4.22: Road speed estimates

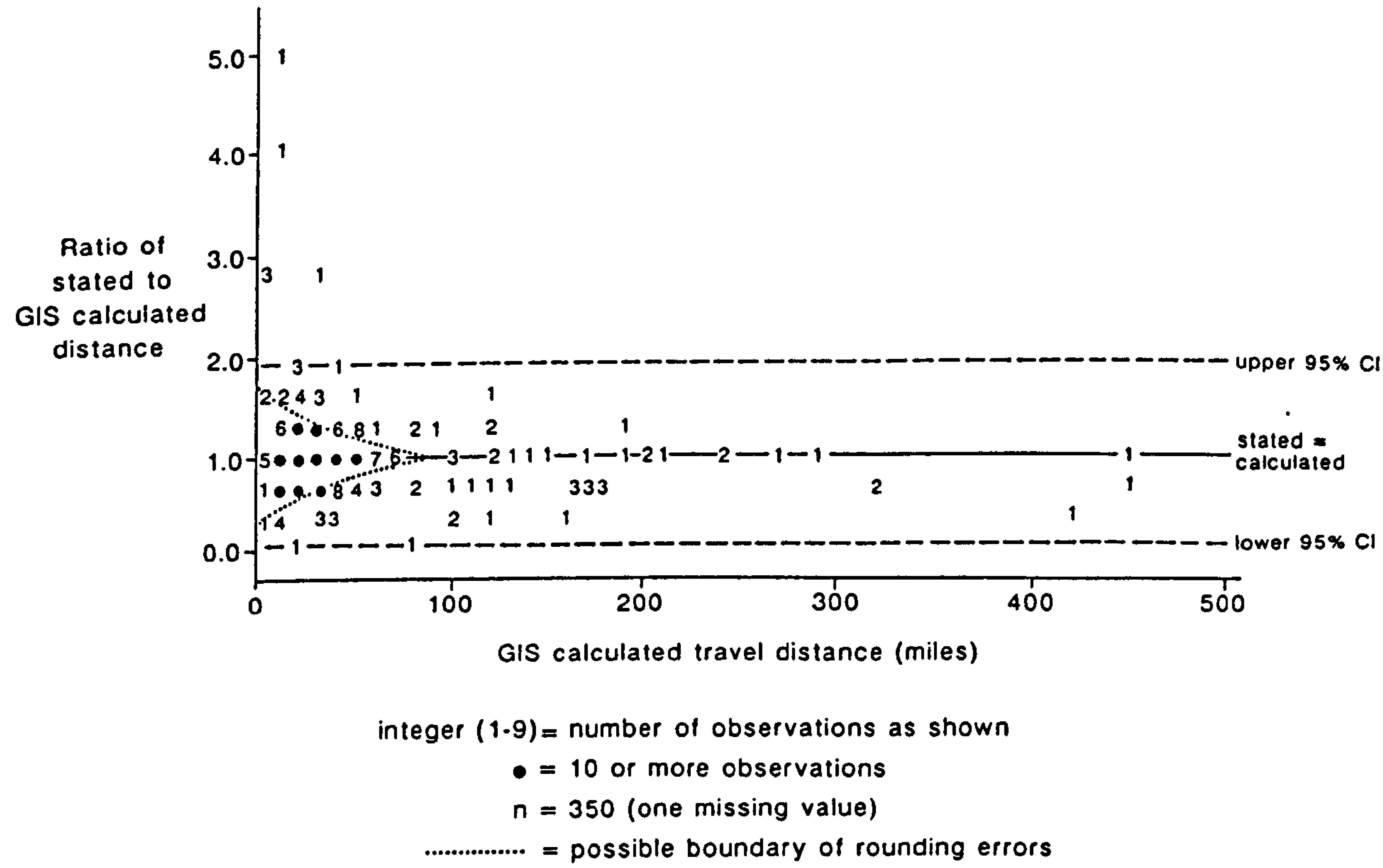
Road Type	Average Road Speed (mph)	
	Rural	Urban
Minor Road	14	11
A-Road Primary Single Carriageway	45	25
A-Road Single Carriageway	32	18
B-Road (with passing places)	24	12
B-Road Single Carriageway	24	12
A-Road Dual Carriageway	50	25
B-Road Dual Carriageway	36	18
A-Road Primary Dual Carriageway	54	28
Motorway	63	35
A-Road Single Carriageway (under construction)	32	18
B-Road Single Carriageway (under construction)	24	12
A-Road Dual Carriageway (under construction)	50	25
Motorway (under construction)	63	35

GIS calculated travel times were then obtained by extracting an individuals travel distance from our digital road network and adjusting for road speed on each segment (defined by road type) of the route from trip origin to site[98].

As noted at the start of this section, visit cost estimates based upon GIS calculated distance and duration have both advantages and disadvantages over those based on visitors perception. Figure 4.10 plots the ratio of stated to GIS calculated distance against the absolute value of the latter.

[98]Details of the steps and GIS commands used in this operation are given in appendix A2.4.2.

Figure 4.10: Graph of the ratio of stated to GIS calculated distance against calculated distance



Examining figure 4.10 shows that, on average, both distance measures coincide reasonably well. The comparatively larger deviation between the measures at low distance is as expected and derives, we argue, mainly from rounding error in statements regarding short journeys. We have drawn in (dotted lines) a cone of observations which may fit into this category. Support for such a line of reasoning is given by noting that, for these 'rounding-error' observations, roughly as many respondents state travel distances below the GIS calculation as above. As the GIS distance is based on a minimum impedance algorithm (minimum time), those respondent estimates below the equality (unity) line must be subject to some form of error, an error which we argue is due to rounding. For observations within this category, the GIS calculated distance may provide a better basis for cost estimates than does stated distance.

As the majority of respondents fall into this category this is an encouraging finding. However, figure 4.10 also shows us that for a few respondents calculated distance is likely to be a poor estimate of true distance. Six extreme cases are identified all lying above the upper 95% confidence interval around the mean. All of these are for stated distances of less than 100 miles and it seems most likely that these respondents are 'meanderers'[99]; those whose main objective is enjoyment of the journey rather than time spent on-site. For these individuals the advantages of removing rounding problems are more than outweighed by the error induced by the logical routing assumption underlying the GIS calculated distance.

While the majority of observations fall within our rounding error cone or close to the unity line the few observations for which the ratio of stated to calculated distance is large, do cause a problem. Overall it is difficult to decide, prior to our subsequent analysis, which distance measure is superior. In hindsight we feel that our survey should have elicited more information upon route itinerary for meanderers. Integration of such information into our GIS distance and duration calculations should produce a superior measure.

Definition of trip generating functions (tgf)

ITC tgf's were estimated by regressing the number of visits which parties made to the site per annum on a variety of explanatory variables. Examination of raw data plots indicated that a natural log dependent variable would fit the data best. Subsequent tests confirmed this and the variable lnVISIT was accordingly defined as follows:

$\ln VISIT = \ln(Q+1)$ where Q is the number of party visits per annum.

Travel cost was initially defined as the sum of time and journey cost, both of which were subjected to sensitivity analysis. Time costs were calculated upon a wage rate basis with the latter being derived from respondents household income. The return trip journey time (whether based upon GIS calculations or respondent statements) was then monetised by multiplying by the calculated income per minute. Following the discussions of chapter 2 several wage rate/leisure time conversion factors where then applied to produce our various estimates of time cost. The conversion factors applied are as follows:

[99]See chapter 2 for further details.

1. 100% (assuming that leisure time is valued at the full wage rate);

2. 43% (the Department of Transport appraisal rate[100]);

3. 0% (assuming that there is no opportunity cost of non-work time).

4. Best fit (data determined).

Journey cost was also based upon return trips. Three valuation assumptions were tested as follows:

1. 8p per mile (Automobile Association estimate of average petrol costs[101]).

2. 23p per mile (Automobile Association estimate of average total running costs[102]).

3. Perceived (unlike the previous two, this assumption was not related to distance travelled but instead set journey cost at that level stated by respondents in answer to a direct question).

The sum of time and journey cost was then divided through by a factor relating to the proportion of the days enjoyment which was attributed by respondents to their time on-site at Thetford Forest. This made allowance for the fact that not all of the trip costs could be attributed to this particular site. Such allowance is especially important when, as here, we have evidence of meanderer's and multi-site visitors amongst the sample.

This adjusted travel cost estimate formed the first of a considerable list of variables which were considered within our tgf analysis. To ensure comparability a consistent (semi-log dependent) functional form and list of explanatory variables was used for all analyses, explanatory variables being as follows[103]:

TC	=	Travel cost (as defined in text)
HSIZE	=	Household size
HOLS	=	Respondent on holiday (0-1)
WORK	=	Respondent working (0-1)
LIVE	=	Respondent lives near site (0-1)
RATING	=	Scenery rating (1-4)

[100]From Benson and Willis (1992).
[101]From Benson and Willis (1992).
[102]ibid.
[103]Other variables considered but rejected from the comparative models include: party size; age<25; age>65; membership of any environmental organisation; membership of separate organisations; other main activity dummies.

TAX	=	Respondent is a taxpayer (0-1)
NT	=	Respondent in the National Trust
MDOG	=	Main reason for visit is dog walking

An income variable was omitted from the above because of intercorrelation with the time cost element of travel costs. Such a variable was tested within a separate set of tgf's where zero time costs were used, but here the income variable proved insignificant.

Four different approaches to tgf definition were investigated as follows:

1. ML and OLS analysis of tgf's based upon GIS calculated distance and duration;
2. ML analysis of tgf's based upon respondents estimate of total journey cost (perceived cost) and GIS calculated duration;
3. ML analysis of tgf's based on respondents estimate of journey duration from which journey cost is also calculated.
4. ML analysis of tgf's based on respondents estimates of journey duration and journey cost.

Sensitivity analyses concerning the per unit value of journey cost and travel time were also carried out on all appropriate options.

Analysis of tgf's based upon GIS calculated distance and duration

Here journey distances and duration are as calculated in our GIS analysis with the full sensitivity range of unit journey and time costs being applied as discussed. The main advantage of such an approach is that it counters the rounding errors inherent in respondents' estimates of journey distance and duration, while the main disadvantage is the inability to detect meanderers.

OLS analysis was carried out as discussed previously. Truncated ML analysis was based upon the approach of Willis and Garrod (1991)[104]. Here we can rewrite our tgf as:

$$\ln VISIT_i = \beta X_i + e_i$$

where: i indexes individuals; X_i is our vector of independent explanatory variables (as defined previously) with coefficient vector β; and e_i are disturbances assumed to be independent,

[104] Which in turn is based on Maddala (1983). We are very grateful to Guy Garrod (University of Newcastle upon Tyne) for copious and excellent assistance with this analysis.

identically distributed $N(0,\sigma^2)$. Given this model, the ML estimator is based on the density function of $\ln VISIT_i$ which is truncated normal as given in equation (4.16):

$$f(\ln VISIT_i) = \begin{cases} \dfrac{(1/\sigma)\varnothing[(\ln VISIT_i-\beta X_i)/\sigma]}{(1-\Phi[-\beta X_i/\sigma])} & \text{if } VISIT_i > 0 \\ 0 & \text{otherwise} \end{cases} \qquad (4.16)$$

Goodness of fit measures were given by R^2 statistics for OLS regressions and log likelihood values for ML analyses.

i. *ML results*

Sensitivity analysis showed that a marginal journey cost assumption (8p/mile) fitted the data better than an estimate based on full running costs (23p/mile). Furthermore, a zero time cost assumption fitted better than either the DOT (43%) or full wage rate assumptions. Iteration revealed that a small wage rate ($2^1/_2$%) time cost assumption provided a superior fit to the data. Table 4.23 reports our best fitting ML model based on GIS calculated journey distance and duration.

Table 4.23: Best fitting ML model based on GIS estimates of journey distance and duration (journey cost @ 8p/mile; time cost @ 2.5% of wage rate).

Variable	Coefficient	Std. Error	T-ratio
Constant	-0.485323	0.592317	-0.819
TC	-0.0776564	0.024008	-3.235
HSIZE	0.0718489	0.054196	1.326
HOLS	-1.47287	0.533289	-2.762
WORK	1.74084	0.453372	3.840
LIVE	2.27700	0.394588	5.771
RATING	0.505034	0.157927	3.198
NT	-0.462887	0.241705	-1.915
TAX	0.441578	0.237004	1.863
MDOG	0.606602	0.246530	2.461
Sigma	1.17890	0.070205	16.792

The model given in table 4.23 fits the data reasonably well and has expected signs and significance on all explanatory variables. The travel cost variable is highly significant, easily passing a 1% test, and indicating that visits are inversely related to the sum of journey and time costs.

Table 4.24 gives travel cost coefficient, log-likelihood value and three consumer surplus per household per visit[105] for the entire range of sensitivity analyses for ML models based upon GIS calculated distance and duration. Upper figures in the consumer surplus cells relate to value in the study year (1993) while lower figures (in brackets) are deflated to 1990 values to allow comparison with our other studies and with those reviewed in chapter 3.

Table 4.24: Sensitivity analysis: ML models based on GIS calculated distance and duration

Travel cost (pence/mile)	Travel time (% of income)	Travel cost coefficient (t-value)	Log likelihood value	Consumer surplus per household per visit (£)[1,2]
8p	0%	-0.084758 (-3.32)	-455.46	3.62 (3.29)
8p	43%	-0.031808 (-2.92)	-455.59	9.65 (8.77)
8p	100%	-0.016002 (-2.72)	-456.28	19.18 (17.42)
8p	2.5%	-0.077656 (-3.24)	-454.59	3.95 (3.59)
23p	0%	-0.031207 (-3.32)	-455.36	9.83 (8.93)
23p	43%	-0.020856 (-3.02)	-455.72	14.71 (13.36)
23p	100%	-0.013251 (-3.00)	-455.35	23.16 (21.04)
23p	6%[4]	-0.029540 (-3.32)	-455.34	10.39 (9.44)

Notes: 1 Upper values in each cell are at 1993 prices, lower values (in brackets) are at 1990 prices. Deflator from CSO (1993).
2 On average households visited Thetford 14.65 times per annum.
3 Best fitting wage rate with a 23p/mile journey cost.

For the following ML models all explanatory variables entered at a 15% significance level: 8p/43%; 8p/100%; 8p/2.5%. For all remaining ML models, all explanatory variables with the exception of HSIZE, entered at a 15% significance level.

[105]Appendix A2.4.2 also gives consumer surplus per household per annum and per person per visit for this and all other tgf specifications.

Examining table 4.24 we can see that our best fitting model (journey cost @ 8p/mile; time cost @ 2.5% wage rate) gives a per household per visit consumer surplus of £3.95 (1993 prices; £3.59 at 1990 prices). This value seems far more defensible than previous published ITC estimates for UK woodland recreation as given in Willis and Garrod (1991). We feel this may well be due to the more satisfactory functional form permitted by the larger sample size of our study. Such results also accord reasonably well with our earlier Thetford 1 ITC experiment although we feel that the present study is superior[106].

The most worrying finding from table 4.24 is the comparatively minor difference in fit between our best fit model and ones using differing journey and time cost assumptions. It is arguable that the deletion of just a very few observations might well reverse the ordering of the goodness-of-fit statistics such that another model appeared optimal. Given that such changes would imply very substantial revisions of our consumer surplus estimates this is a matter of some concern. However, a counter argument can be found. Our sensitivity analysis amounts to simply altering multipliers within the TC variable. Although the differing coefficient values this engenders results in considerably differing consumer surplus estimates, such changes cannot (by their nature) have particularly significant impacts upon model fit. Therefore the differences between such models will of necessity be small. Nevertheless, even if we accept such an argument this may still imply problems for the travel cost method as it means that substantial changes in consumer surplus estimates may be engineered by switching between models of quite similar explanatory power. This is a serious issue for practical evaluation studies as the implications for CBA assessments involving such evaluations are clearly major.

ii. OLS results

Given the findings of our ML analyses, only zero and 43% wage rate time costs were used in the OLS sensitivity analysis. The best fitting model used a unit journey cost value of 8p/mile and a zero time cost. Table 4.25 details this model.

All the explanatory variables in table 4.25 are correctly signed and generally of high statistical significance. Table 4.26 gives our sensitivity analysis range of consumer surplus

[106] In particular the Thetford 1 study relied upon OLS estimation procedures (see subsequent discussion).

measures[107].

Table 4.25: Best fitting OLS model based on GIS estimates of journey distance and duration (journey cost @8p/mile; zero time cost)

Variable	Coefficient	Std. Error	T-ratio
Constant	0.574852	0.352221	1.637
TC	-0.0432747	0.013387	-3.226
HOLS	-0.798169	0.264766	-2.984
WORK	1.40939	0.359360	3.923
LIVE	2.00810	0.319801	6.282
RATING	0.334414	0.105753	3.169
NT	-0.305482	0.156728	-1.916
TAX	0.277334	0.153215	1.773
MDOG	0.425503	0.179052	2.396

$R^2 = 23\%$ $R^2(adj) = 21\%$ $n = 351$

Table 4.26: Sensitivity analysis: OLS models based on GIS calculated distance and duration

Travel cost (pence/mile)	Travel time (% of income)	Travel cost coefficient (t-value)	R^2	Consumer surplus per household per visit (£)[1,2]
8p	0%	-0.046776 (-2.93)	21.72%	21.38 (19.42)
8p	43%	-0.011519 (-2.12)	20.79%	86.81 (78.87)
23p	0%	-0.016801 (-2.90)	21.69%	59.52 (54.07)
23p	43%	-0.008904 (-2.51)	21.21%	112.13 (101.87)

Notes: 1 Upper values in each cell are at 1993 prices, lower values (in brackets) are at 1990 prices. Deflator from CSO (1993).

2 On average households visited Thetford 14.65 times per annum.

For all OLS models all explanatory variables entered at a 15% significance level.

[107]For comparative purposes table 4.26 contains models with exactly the same explanatory variables as table 4.24 (this accounts for the slight difference in coefficient estimates between our best fit OLS model in table 4.25 and its counterpart in table 4.26).

These results confirm our prior ML findings that models using marginal journey costs (8p/mile) and very low (here zero) time costs fit the data best. Also, and for the same reasons as before, there is comparatively little difference in overall degrees of explanation across these models[108].

Comparison of our ML and OLS estimates can be conducted on three levels: statistical; cross-study; and theoretical. On statistical grounds the ML models appear to have explained the data somewhat better than their OLS counterparts. Although comparison of overall degrees of explanation statistics (log likelihood values versus R^2) is problematic, explanatory variable t-values in directly comparable models were generally higher in ML than OLS models, and invariably so with regard to the travel cost variable. Cross-study comparisons also suggest that the ML models have performed better, producing best-fit consumer surplus estimates which are much more in line with both other studies and prior expectations than those produced by our OLS models. However, such tests of validity are weak unless backed by theoretical justification.

The theoretical case for preferring ML over OLS estimates is strong. Several authors (see chapter 2) have argued that OLS methods are inappropriate for analysing on-site recreation data as such surveys do not elicit any information on individuals who choose not to visit the site. OLS methods neglect the truncation of the visits variable at zero. Balkan and Kahn (1988) show that in such circumstances OLS methods result in an over-estimate of consumer surplus. Conversely truncated ML techniques can explicitly allow for the absence of non-visitors. Comparison of tables 4.24 with 4.26 suggests that the findings of Balkan and Kahn (1988) are confirmed by our study[109]. Consequently we adopt ML estimation techniques in our subsequent analyses.

Analysis of tgf's based on perceived journey cost and GIS calculated duration

Here journey duration is calculated as before but journey cost (petrol, etc) is taken from responses to a direct survey question. Such an approach goes part way towards addressing the problem of meanderers. However, in relying upon respondents statements

[108] This is of course comparing refinements within a common functional form. As noted in our Thetford 1 ITC study, differences between functional forms can be much more pronounced.

[109] In their meta-analysis of 77 TC studies, Smith and Kaoru (1990) find that adjusting for truncation could reduce OLS estimates by over $50.

some rounding errors may be reintroduced to the dataset.

Given our prior findings regarding likely time costs, two wage rates were investigated, zero and 43%, with the former providing the better fitting model which is detailed in table 4.27. Consumer surplus estimates for both perceived cost models are given in table 4.28.

Table 4.27: Best fitting ML model based on perceived journey cost and zero time costs

Variable	Coefficient	Std. Error	T-ratio
Constant	-0.0917968	0.554329	-0.166
TC	0.0836772	0.026318	-3.179
HOLS	-1.53383	0.536695	-2.858
WORK	1.74738	0.453857	3.850
LIVE	2.17069	0.397130	5.466
RATING	0.461651	0.156705	2.946
NT	-0.518101	0.242304	-2.012
TAX	0.409297	0.238369	2.154
MDOG	0.601554	0.245362	2.500
Sigma	1.18499	0.070902	16.689

Log-likelihood value = -455.95 (estimates converged after 4 iterations; variables as defined in text)

Our best fitting model based on perceived costs performs only marginally worse than that based upon GIS calculations and produces very similar consumer surplus estimates. This would appear to give some additional validity to both approaches. As before, and for the same reasons, the overall degree of fit between perceived cost models is similar.

Table 4.28: Sensitivity analysis: ML models based on perceived journey cost and GIS calculated duration

Travel cost (pence/mile)	Travel time (% of income)	Travel cost coefficient t-value)	Log likelihood value	Consumer surplus per household per visit (£)[1,2]
Perceived	0%	-0.083677 (-3.18)	-455.95	3.66 (3.33)
Perceived	43%	-0.034485 (-3.03)	-456.60	8.90 (8.08)

Notes: 1 Upper values in each cell are at 1993 prices, lower values (in brackets) are at 1990 prices. Deflator from CSO (1993).

2 On average households visited Thetford 14.65 times per annum.

All explanatory variables entered at a 15% significance level.

Analysis of tgf's based upon respondents estimate of journey duration

In these analyses both journey cost and time cost are derived from respondents statements regarding journey duration. A specific question asked respondents to state how long it had taken them to travel to the site. These responses were then doubled to give round trip journey times to which wage rate proportions could be applied to derive time costs. Implicit journey distance was calculated by assuming an average speed of 40 mph, a figure based upon our earlier GIS research. Applying our various per-unit rates gave us our perceived journey cost. Such an approach provides an arguably more complete approach to meanderers than does the previous section, however it is more liable to the rounding errors induced by moving away from our GIS calculated measures.

Sensitivity analysis showed that a zero time cost assumption fitted the data best, outperforming any positive wage rate[110]. This causes a slight problem with regard to the journey cost assumption as, with no time cost element, both 8p/mile and 23p/mile journey costs will give identical degrees of overall model fit (i.e. they act as simple multipliers to an otherwise identical travel cost term). Given than an 8p/mile assumption has performed better in our previous analyses we chose this as our preferred best model which is detailed in table 4.29.

Table 4.29: Best fitting ML model based on perceived journey duration from which journey costs are derived (journey costs @ 8p/mile; zero time costs)

Variable	Coefficient	Std. Error	T-ratio
Constant	-0.247513	0.589563	-0.420
TC	-0.106951	0.031096	-3.439
HSIZE	0.0631174	0.054057	1.168
HOLS	-1.40119	0.530947	-2.639
WORK	1.73693	0.452641	3.837
LIVE	2.14083	0.396713	5.396
RATING	0.466641	0.155442	3.002
NT	-0.455569	0.240327	-1.896
TAX	0.389710	0.235351	1.656
MDOG	0.625690	0.245218	2.552
Sigma	1.17540	0.069881	16.820

Log-likelihood value = -453.93 (estimates converged after 4 iterations; variables as defined in text)

[110]Variable wage rate assumptions were tested here.

Table 4.30 details travel cost coefficients, overall fit and consumer surplus estimates for all the models estimated in this analysis. The best fit per household per visit estimate of consumer surplus is a little over £1 higher than for the models based on our GIS calculations and has a very marginally superior log-likelihood value.

Table 4.30: Sensitivity analysis: ML models based on perceived duration and derived distance

Travel cost (pence/mile)	Travel time (% of income)	Travel cost coefficient (t-value)	Log likelihood value	Consumer surplus per household per visit (£)[1,2]
8p	0%	-0.106951 (-3.439)	-453.93	4.86 (4.42)
8p	43%	-0.032386 (-2.765)	-456.09	9.47 (8.60)
8p	100%	-0.0153005 (-2.499)	-456.90	20.06 (18.22)
23p	0%	-0.037200 (-3.439)	-453.93	8.25 (7.50)
23p	43%	-0.0220848 (-3.118)	-454.92	13.89 (12.62)
23p	100%	-0.013271 (-2.840)	-455.84	23.12 (21.00)

Notes: 1 Upper values in each cell are at 1993 prices, lower values (in brackets) are at 1990 prices. Deflator from CSO (1993).
2 On average houscholds visited Thetford 14.65 times per annum.

For the following truncated ML models all explanatory variables entered at a 15% significance level: 8p/43%; 8p/100%; 8p/2.5%. For all remaining truncated ML models, all explanatory variables with the exception of HSIZE, entered at a 15% significance level.

Analysis of tgf's based on respondents estimates of journey duration and cost

In this analysis both journey duration (and hence time costs) and journey cost are taken directly from visitors responses to separate questions eliciting this information as part of the on-site survey. As before such an approach should capture the behaviour of meanderers better than our GIS calculations but is susceptible to response-rounding errors.

By comparing results from this approach to those from the previous analysis based solely upon perceived duration, we can also assess the relative accuracy of respondents estimates of journey duration and journey cost.

As previously we only estimated models for zero and 43% wage rate time costs, a 100% rate seeming unfeasible given prior results. Of those the zero time cost model performed marginally better and is reported in full in table 4.31.

Table 4.31: Best fitting ML model based on perceived journey duration and cost (journey costs as stated by respondent; zero time cost)

Variable	Coefficient	Std. Error	T-ratio
Constant	-0.489717	0.593045	-0.826
TC	-0.0676986	0.023003	-2.943
HSIZE	0.0969824	0.054356	1.784
HOLS	-1.47050	0.536713	-2.740
WORK	1.82321	0.454354	4.013
LIVE	2.25116	0.397103	5.669
RATING	0.469444	0.156934	2.991
NT	-0.484902	0.242462	-2.000
TAX	0.399381	0.238005	1.678
MDOG	0.649186	0.246816	2.630
Sigma	1.18268	0.070644	16.741

Log-likelihood value = 455.47 (estimates converged after 4 iterations, variables as defined in text)

Table 4.32 details travel cost coefficients, overall fit and consumer surplus estimates for both of the models estimated in this analysis. Best fit consumer surplus estimates are similar to those based solely upon perceived journey duration but model fit is somewhat worse (see table 4.30 for comparison). This indicates that respondents perceived journey distance more accurately than they do journey cost.

Table 4.32: Sensitivity analysis: ML models based on perceived journey duration and journey cost

Travel cost (pence/mile)	Travel time (% of income)	Travel cost coefficient (t-value)	Log likelihood value	Consumer surplus per household per visit (£)[1,2]
Perceived	0%	-0.023003 (-2.943)	-455.47	4.53 (4.12)
Perceived	43%	-0.011113 (-2.831)	-455.80	9.75 (8.86)

Notes: 1 Upper values in each cell are at 1993 prices, lower values (in brackets) are at 1990 prices. Deflator from CSO (1993).
2 On average households visited Thetford 14.65 times per annum.

For the following truncated ML models all explanatory variables entered at a 15% significance level: 8p/43%; 8p/100%; 8p/2.5%. For all remaining truncated ML models, all explanatory variables with the exception of HSIZE, entered at a 15% significance level.

Thetford 2 ITC study: Conclusions

This study has examined three separate and very fundamental issues regarding the application of the ITC. Firstly, we have examined both OLS and ML estimation methods and found convincing evidence supporting the use of the latter. Secondly, regarding the valuation of journey costs and travel time, we have applied a full sensitivity analysis across a range of tgf definitions consistently finding that petrol-only journey costs and very low or zero time costs gave us best fitting models[111]. Travel cost functions based upon respondents estimates of journey cost performed worse than these flat rate approaches and subsequent analysis suggested that visitors are relatively unsure of journey costs compared to their perception of journey duration. Thirdly, the issue of journey distance and duration has been addressed both through more conventional analysis of respondents estimates and through a novel application of GIS software. We have argued that, while the former approach is better suited to the identification of respondents who take circuitous routes to the site, the GIS approach reduces the rounding errors which are endemic amongst the majority of visitors. Comparison of the statistical power of tgf's derived from these two approaches is interesting. As figure 4.10 showed there are a very few meanderers compared to the numbers whose distance estimates

[111]This result gives further support for our questioning of the assumptions used by Benson and Willis (1992) and thereby for our revised estimate of their results (see chapter 3).

may suffer from rounding error. However, the omission of these few meanderers in the GIS-based tgf's is likely to lead to a relatively large fall in overall fit compared to the impact of rounding errors upon tgf's based on visitors responses. In the event our best fit GIS-based tgf has a log-likelihood value only slightly lower than the best fit response-based tgf[112]. These give per household per visit consumer surplus estimates of £3.95 (1993 prices; £3.59 at 1990 prices) and £4.86 (£4.42) respectively, amounts that could defensibly be used to mark out an envelope of valuation. We strongly suspect that a measurement approach which combines the accuracy of our GIS approach with route itinerary information elicited from respondents would provide a significantly superior basis for ITC studies.

4.4: CONCLUSIONS

This chapter has presented three studies of the monetary value of open access woodland recreation. Each of these studies has contributed to our understanding of the complexity of monetary evaluation analyses of the complexity of monetary evaluation analyses and in particular the potential for design bias. The Thetford 1 study highlighted issues such as the anchoring effect of information on present payments and the potential for highly significant payment vehicle effects. These findings fed into the subsequent Wantage CV study which appeared to be less subject to bias and showed interesting relationships between WTP and payment period which may be symptomatic of wider concerns regarding the privatisation of public open space. The Wantage study is also notable for establishing that in principle farmers would be prepared to consider ventures into the provision of recreational woodland at appropriate levels of compensation payments, although these were considerably above present returns on standard agricultural crops indicating that a risk averse motivation may be at work here.

While these early results are generally encouraging our later work in the Thetford 2 study raises difficult questions regarding the optimal execution of both CV and TC studies highlighting substantial variability in the welfare measure estimates generated by both methods. This echoes the variability observed in our review of previous studies presented in

[112]Best fit GIS-based tgf (8p/mile journey cost and 2.5% time cost; see table 4.24) has log-likelihood value -454.59 while best fit response-based tgf (8p/mile journey cost and zero time cost; see table 4.30) has log-likelihood value -453.93.

chapter 3. While in both the Thetford 2 CV and TC analyses cases can be made regarding which results have greater empirical or theoretical validity, this variability leads us to conclude that decisionmakers should consider a sensitivity analysis across differing valuation results when taking decisions regarding the provision of environmental resources. Following this we adopt such a sensitivity analysis approach in the subsequent chapter which is primarily concerned with the estimation of visitor numbers but then translates this into demand valuations.

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Chapter 5: Recreation: Estimating and Valuing Demand

5.1: INTRODUCTION

In this chapter we utilize geographical information systems (GIS) to model arrivals at a particular woodland site and test the efficiency of the resultant *arrivals function* in predicting visits to other sites. Findings from our studies of the value of open-access woodland recreation are then applied to our predicted visits surface to obtain a valuation of potential demand.

5.2: ESTIMATING AN ARRIVALS FUNCTION

5.2.1: PREVIOUS STUDIES

In this chapter we are concerned with estimating overall visitation rates which are applicable across populations, rather than being specific to individuals. By definition conventional individual valuation studies only have relevance to visitors and tell us nothing of non-visitors, so that they are incapable of determining the absolute number of people who will visit a site. Therefore, our visitor arrivals model has to be composed of variables which have relevance across the population.

To date there has been relatively little research regarding the level and determinants of demand for woodland recreation in the UK. Furthermore, of those few studies which have looked at this issue, most have looked at national recreational demand (Willis and Benson, 1989; Whiteman[1], 1991) rather than that at any particular forest site. One notable exception is provided by the work of Colenutt and Sidaway (1973) regarding the modelling of demand for day trip visits to the Forest of Dean. Here a combined on-site and household (postal) survey was used to collect information regarding trip origins and the factors determining trips. Analysis of this data revealed that by far the most important factor determining arrivals was trip duration, to the effective exclusion of other explanatory variables.

The Colenutt and Sidaway result is important as, if it were reconfirmed in our own analysis, an 'arrivals function' could be estimated relating travel time to the probability of a

[1]Whiteman (1995) presents national models of both the demand and supply of UK woodland.

visit taking place[2]. The spatial analytical power now provided by a GIS makes it possible to apply such a function to detailed population data, such as that provided in the UK Census, in order to predict arrivals at any existing or hypothetical site[3]. Obviously, in practice, the validity of applying an arrivals function estimated for one site to another would need to be carefully assessed in terms of the accuracy of the predictions made and such a cross site predicted versus actual test is carried out and presented subsequently.

5.2.2: RECREATION DEMAND: THE THETFORD FOREST STUDY

The base data for our investigation was elicited as part of the Thetford 2 CV/ITC study. Individual journey distance and duration measures were calculated for use within the ITC valuation study as described in chapter 4. These measures were, by dint of their method of derivation, adjusted for the availability and quality of the road network and are therefore inherently superior to the simple, unadjusted equivalents used in the Colenutt and Sidaway study. However, such individual level variables were inappropriate for use within our arrivals function. We therefore needed to convert our travel time road network data into continuous travel time zones which would have relevance to visitors and non-visitors alike. To obtain this continuity of coverage the vector data[4] derived for each individual segment of the road network had to be rasterised.

Rasterisation is a process of converting vector features to cells on a regular grid[5]. In this study the travel time values assigned to points along roads were reassigned to the grid cells which contained those points. Rasterisation allowed a 'majority filter' to be run recursively across the entire study area to smoothly fill in the gaps between roads, providing values for all grid cells and producing a continuous travel time surface centred upon the site

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[2]For obvious reasons economists have tended to focus upon travel cost rather than travel time, indeed a major focus of such research has been the monetary evaluation of travel time to enable its incorporation within the overall visit cost function. Geographers, on the other hand, have examined both time and cost distances (for a review see Gatrell, 1983), but empirical investigations of the latter have been relatively limited and most research on location theory has tended to rely simply on measurements of Euclidean distance. This study seeks to examine both concepts, using travel time as a predictor of the quantity of visits, but also examining overall costs in an attempt to place monetary value on the relevant recreation.

[3]English Nature and the ESRC have recently provided the author with funding to extend the work described in this chapter so that socioeconomic factors and the availability of substitute recreational facilities may be explicitly incorporated within the arrivals function.

[4]See Environmental Systems Research Institute (1993) for further details.

[5]Vector features (roads) were rasterised onto a 500 m grid. This equated to a total of 161195 cells for our entire study area of which 58364 were directly filled through the rasterisation process, the remainder being assigned values through the process described in the text.

and fanning out to fill the entire study area. The majority filter worked by means of a 'moving window' (usually eight by eight cells in extent)[6], where the centre-most empty cell was assigned the value held by the majority of already assigned cells in the specified window. The majority filter worked well for the vast majority of cells. However, a few gaps remained in areas very remote from any roads where the filter window did not contain any cells filled directly by the rasterisation process. These grid cells were given the values of their nearest neighbours.

Once all the grid cells had been assigned a value these were reclassified into convenient categories[7]. Inspection of the calculated travel times showed that the extended road network encompassed all values up to 120 minutes. Within this range, 13 time zones were defined. Given the concentration of visit origins around the site, the innermost zones (between 0 and 30 minutes) were tightly defined at 5 minute intervals, after which 10 and eventually 15 minute bands were used (between 30 and 60 minutes and 60 to 120 minutes respectively). Certain of the resulting time travel zones are illustrated in figure 5.1.

Once travel time zones were defined the relevant zone for each survey respondent was identified. Arc/Info provides two routes of obtaining this information; the *identity* and *addroutemeasure* commands. Both were tested and provided almost identical results. The *identity* command appeared to suffer slightly more from the rasterisation anomalies discussed above and so results from *addroutemeasure* were preferred. Results from this exercise are presented in the first two columns of table 5.1. Here column (1) shows the upper limit of each travel time zone (in minutes of vehicle travel to the site) and column (2) records the number of party visits to the site from each zone during the period of the survey[8] (other columns are

[6]A filtering window of 8 x 8 cells was used. This was held constant across our entire study area except for edge cells where the window could feasibly reduce to as few as 4 cells (only filled cells are incorporated into the filter). The possibility of an edge distortion does exist but, given the very large number of cells used in the entire Thetford dataset, any such distortion would be extremely minor.

[7]The time zone classification procedure revealed a very minor but intractable problem in the rasterisation algorithm available in the Arc/Info GIS (version 6.1). This was evidenced by the definition of two separate 0 to 5 minute travel time zones. Since we were assuming people would essentially travel to Thetford by the quickest route possible, time values assigned to cells during the rasterisation process should have been the smallest possible. As directed by the software manuals, a weight table (giving preference to lower time values) was specified to ensure this, but this was inconsistently implemented by the programme. There are references to this shortcoming in the Arc/Info online documentation file, *known_problems*, but no solution is offered. Furthermore, the effect of this inconsistency was compounded slightly by the majority filtering. Even so, as is evident from figure 5.1, the overall impact of this problem was minor.

[8]The possibility of repeat visits was recognised. This was tested for and proved not to be a feature of the survey sample.

discussed subsequently). Of the total sample of 351 parties, 326 (92.8%) originated from time zones encompassed by our GIS road network. This provided a sufficient sample to both estimate an arrivals function and extrapolate it beyond the limits of our road network.

Figure 5.1: Travel time zones for the Thetford Forest study (travel time in minutes)

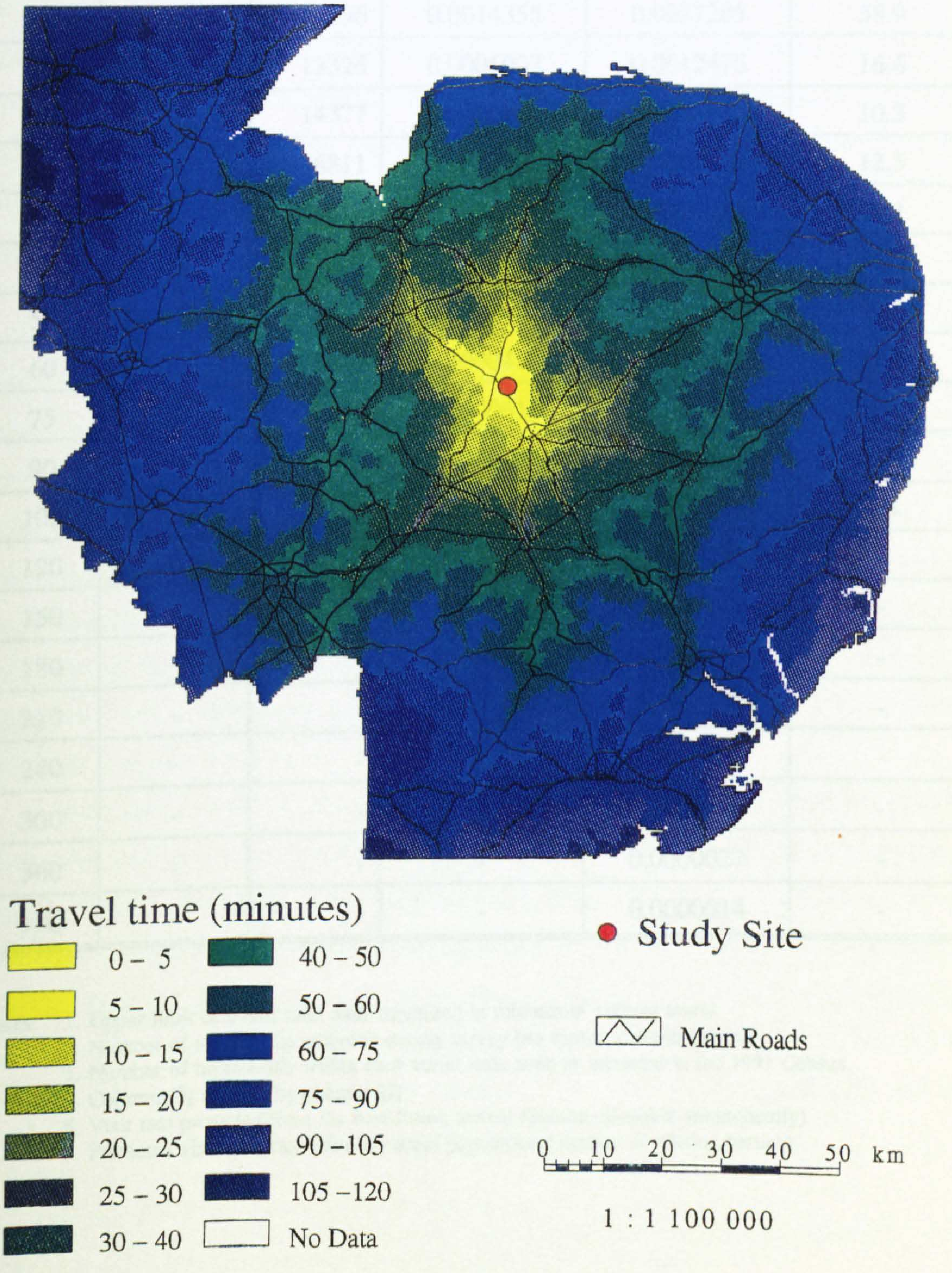

Table 5.1: Observed and predicted visitor rates

Time Zone[1] (1)	Actual Visits[2] (2)	Zonal Pop'n[3] (3)	Observed Visit Rate[4] (4)	Predicted Visit Rate[5] (5)	Predicted Visits[6] (6)
5	13	954	0.0136268	0.0103972	9.9
10	31	21596	0.0014355	0.0027285	58.9
15	8	13326	0.0006003	0.0012476	16.6
20	10	14377	0.0006956	0.0007160	10.3
25	26	26811	0.0009698	0.0004655	12.5
30	38	58416	0.0006505	0.0003274	19.1
40	46	191009	0.0002408	0.0001879	35.9
50	65	405831	0.0001602	0.0001222	49.6
60	17	375134	0.0000453	0.0000859	32.2
75	48	776817	0.0000618	0.0000559	43.4
90	15	562508	0.0000267	0.0000393	22.1
105	7	253762	0.0000276	0.0000292	7.4
120	-	-	-	0.0000225	-
150	-	-	-	0.0000147	-
180	-	-	-	0.0000103	-
210	-	-	-	0.0000077	-
240	-	-	-	0.0000059	-
300	-	-	-	0.0000038	-
360	-	-	-	0.0000027	-
500	-	-	-	0.0000014	-

Notes:
1. Upper limit of travel time zone measured in minutes of vehicle travel.
2. Number of party visits recorded during survey (no repeat visits in sample).
3. Number of households within each travel time zone as recorded in the 1991 Census.
4. Column (2) divided by column (3)
5. Visit rate predicted from the best fitting arrival function (detailed subsequently)
6. Predicted visit rate multiplied by zonal population (number of visiting parties)

The desired arrivals function would predict visits as a function of travel time. However, to achieve this it was necessary to account for varying population densities across our time zones (i.e. we needed to calculate a visit rate in terms of party visits per capita). Accordingly a population surface was created which coincided in geographic extent with the road network. Totals for persons usually resident in Enumeration Districts (the finest level of detail available) were extracted from 1991 Census data using the SASPAC software (London Research Centre, 1992) and grid references for centroids were obtained from the U42 files held at Manchester Computing Centre. A check on the accuracy of grid references was then conducted by calculating mean centres and standard distances for the Enumeration Districts within each Ward. This process revealed a few gross errors in grid references which were corrected.

Allocation of residential populations to the 500 metre grid cells comprising the travel time zones was achieved through a volume-preserving algorithm, using a form of the SBUILD programme described by Martin (1990). A mask image was used to prevent allocations outside the study area and initial input to the software consisted of 6,675 centroids with a population of 2,723,971. The surface produced by SBUILD (after cell totals were rounded to the nearest integer) contained a total population of 2,724,133. Detailed inspection indicates that the characteristics of urban areas are well represented and the only criticism which might be made is that some areas classed as 'unpopulated' undoubtedly contain isolated properties. This type of deficiency is, however, virtually inevitable given reliance on data for areal aggregates such as Enumeration Districts and in the context of this research is not thought to represent a significant problem.

Population totals for our defined travel time zones were straightforward to calculate within the *grid* module of Arc/Info. By allocating each of the surveyed parties to a travel time zone and allowing for zonal population, a zonal visit rate was calculated, using the *zonalsum* command[9]. Results from this exercise are shown in table 5.1. Here column (3) records the zonal population extracted as above. Column (4) divides visits from each zone (column (2)) by zonal population (column (3)) to give our observed visit rate. This represents the dependent variable in our arrivals function. The contents of columns (5) and (6) are

[9]To calculate the zonal visit rate, the *zonalsum* command was executed as follows;

popzsgr = zonalsum(timezones,angpopgr), (where angpopgr = east anglia population).

Each of the new output cells contains the sum population for its time zone.

described subsequently.

Table 5.1 indicates a marked inverse relationship between travel time and visit rate. Note that the furthest time zone (120 minutes) has been omitted from our observed data. This zone was not completely encompassed by the road network (see figure 5.1), and the calculated rate appeared anomalous in initial statistical analysis. Data for this zone was consequently excluded from the calibration of the arrivals function (see appendix 3.1).

An examination of the relationship between travel time and visit rate was undertaken, full details of which are given in appendix 3.1. This revealed that a double log model provided an excellent fit to the data.[10] Equation (5.1) summarises the resulting arrivals function.

$$\ln VR = \underset{(-2.41)}{-1.46} - \underset{(-11.39)}{1.93} \ln TZ \tag{5.1}$$

R^2 (adj) = 92.1%
Figures in parentheses are t-values.

where: VR = observed visit rate (number of party visits from zone i divided by zonal population)
TZ = travel time zone (minutes)

Investigations into potential omitted variables and correlations of residuals failed to reveal any significant problems with equation (5.1).[11] Given the strength of this relationship we felt confident in extrapolating our arrivals function to more distant travel time zones. Columns (4) and (5) of table 5.1 list observed and predicted visitor rates, while columns (2) and (6) report actual and predicted visitor numbers respectively. The arrivals function predicted 317.8 party visits from the first 12 travel time zones during the sampling period. This compares with an actual figure of 324, i.e. an error of less than 2%.[12]

Our arrivals function refers to those visitors interviewed during the sampling period. One of the main reasons for conducting our survey at Thetford rather than at a Welsh site was

[10]The double log form narrowly outperformed a semi-log (dependent) model, other forms fitting the data poorly. This is similar to the findings of Colenutt and Sidaway (1973) who report results for both forms although it is not made clear which is superior.

[11]Detailed analysis reported in appendix 3.1.

[12]Note that both these figures (actual and predicted) omit non-sampled visitors (eg. those arriving at hours outside those sampled). These are adjusted for subsequently (details in appendix 3.2).

that it is one of the very few forests for which accurate daily and weekly visitor records are available (weekly data being held for several years). This information enabled us to allow for those visitors to Thetford which we failed to interview during our sampling period and also to establish that a very stable relationship existed between visits during our sampling period and annual visits (appendix 3.2 gives full details of this analysis). This allowed us to extrapolate our sample period arrivals function onto an annual basis. Comparison of predicted with actual annual visits showed a discrepancy of less than 2%.

5.3: APPLYING THE ARRIVALS FUNCTION: PREDICTING ARRIVALS IN WALES

Our first concern was to test the validity of our arrivals function against actual arrivals at a sample of Welsh sites. A study area boundary was defined and coincident road network and population surface constructed in a similar manner to the Thetford analysis. In order to allow for distant travellers to potential woodland sites along the Welsh border, the study area was defined so as to reach deep into England[13]. Appropriate county boundaries were obtained from the Bartholomew database[14]. Road data were then extracted, clipped and corrected as described previously. B-roads and roads of minor class outside Wales were deleted, except where their omission created significant gaps in road topology. Roads that were just outside the defined study area were also included (notably the M6 motorway outside Coventry) if their absence seemed likely to have a significant impact on population access to the road network. The resulting road network is illustrated in figure 5.2.

Population data and centroids for Enumeration Districts were again obtained from Manchester Computing Centre. The study area encompassed 30,311 Enumeration Districts with a total resident population of 13,821,562. Once centroid grid references had been checked, the Arc/Info *sbuild* programme was used to generate a population surface at 500 m grid cell resolution. Figure 5.3 illustrates the resulting output, the population for the surface (after cell totals were rounded to the nearest integer) being 13,821,361 people.

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[13]The study area was defined as the following counties and areas: Avon, Cheshire, Clwyd, Dyfed, Gloucester, Greater Manchester, Gwent, Gwynedd, Hereford & Worcester, Merseyside, Mid Glamorgan, Powys, Shropshire, South Glamorgan, Staffordshire, West Glamorgan, West Midlands and Anglesey & Holyhead

[14]Minor islands off the coast of Britain were removed.

Figure 5.2: Digital road network for Wales and the English Midlands[1]

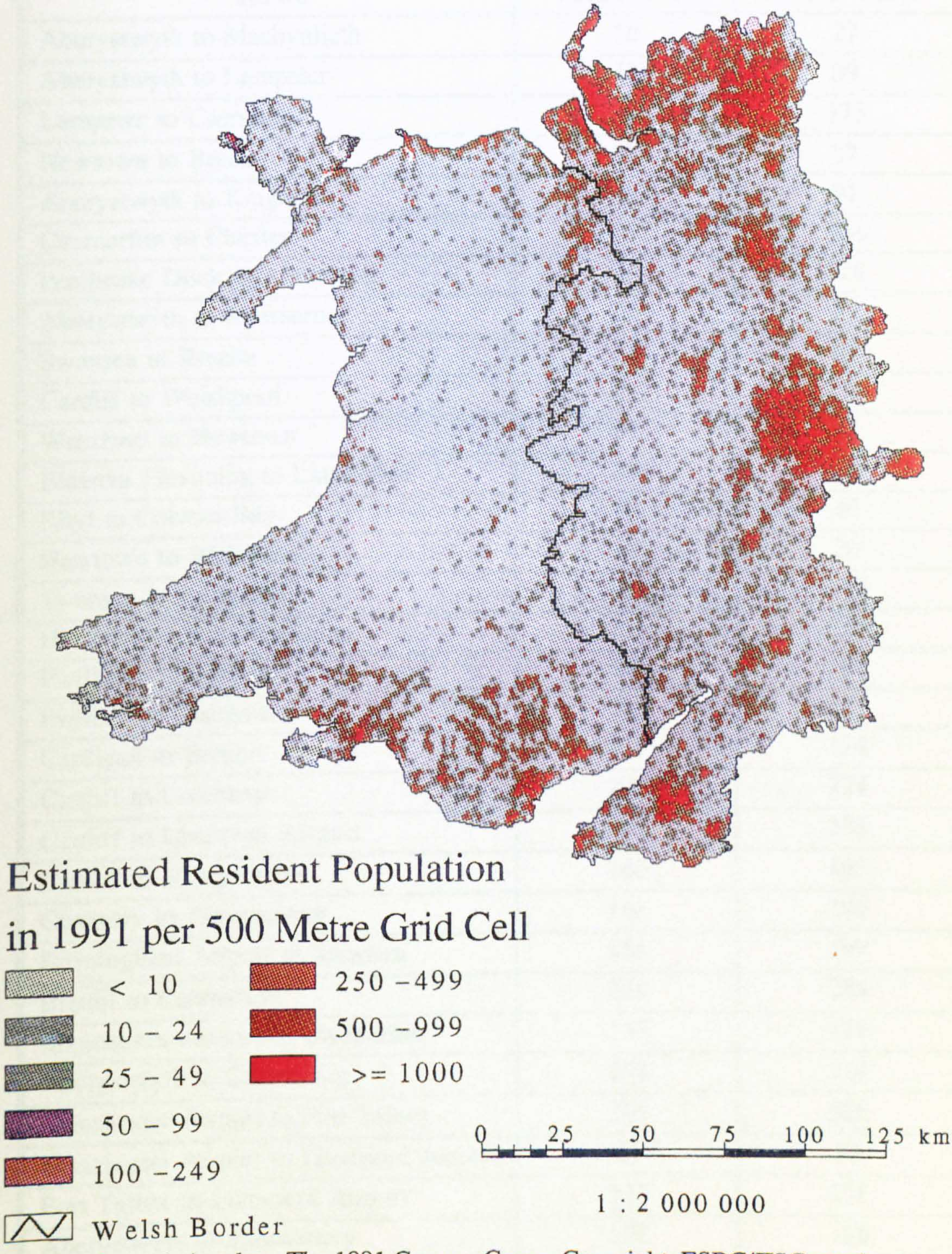
Note: For cartographic reasons minor roads are omitted from the figure.

In order to compare the recreational potential with the agricultural output results calculated subsequently in this study, it was highly desirable to present the former as a map. The monetary equivalent of this demand could then be evaluated using our findings from chapters 3 and 4, and compared with that for agriculture to see where a switch to woodland might be desirable. Such a recreation demand surface required the estimation of predicted arrivals for a regular grid over the entire extent of Wales. This necessitated repetitive, intensive data processing. Furthermore, because the size of the Welsh study area and road network considerably exceeded that for the Thetford analysis, an alternative approach to the calculation of travel time zones and zonal population around each potential site was necessary. Accordingly the road data was transformed from a vector to raster format to allow the use of a *costdistance* function in the definition of time zones. This required generation of an impedance surface, with the value of each grid square representing the impedance involved during traversal of that cell. Overall, the *costdistance* approach seeks to minimise the impedance between origin and destination locations. Several steps were necessary to generate the impedance surface.

Roads were rasterised on a 500m regular grid. The value assigned to each cell was the class of the road segment (as recorded in the Bartholomew database) with the greatest cumulative length running through the grid square. As a consequence, a long section of road that just clipped the edge of a $500m^2$ cell took precedence over a short segment of road that actually had the greatest length within the grid square. This was a feature of the rasterising algorithm and could not be readily circumvented. Urban boundaries[15] were rasterised and overlayed onto the road network to allow separation of urban from rural roads. The adjusted urban and rural road speeds calculated as part of the Thetford 2 ITC study (chapter 4) were used to calculate initial impedance values. However, scrutiny of the resultant travel times on the rasterised Welsh road network suggested that most were too slow. This is illustrated for a sample of 32 routes in table 5.2 where journey times were calculated using both the original vector road network and the subsequent rasterised version. Such a contrast can be attributed to unavoidable changes in road topology upon rasterisation and the bias towards classifying cells in terms of road segments with the longest cumulative length rather than those of greatest extent within the grid square.

[15]Also obtained from the Bartholomew database.

Figure 5.3: Population density surface for Wales and the English Midlands (population in each 500 m^2 grid square: calculated using Arc/Info *sbuild* software with 1991 Census ED centroids)



Source of population data: The 1991 Census, Crown Copyright, ESRC/JISC purchase.
The population density values were calculated using the SBUILD software
with 1991 Census Enumeration District centroids.

Table 5.2: Calculated journey times for selected routes in the Welsh study area (in minutes).

Route	Vector Time	Raster Time
Aberystwyth to Machynlleth	16	27
Aberystwyth to Lampeter	49	59
Lampeter to Caernarfon	149	173
Newtown to Brecon	77	87
Aberystwyth to Knighton	100	91
Caernarfon to Chester	94	144
Pembroke Dock to Aberaeron	93	118
Aberystwyth to Aberaeron	24	31
Swansea to Brecon	58	69
Cardiff to Welshpool	155	175
Wrexham to Newtown	57	72
Blaenau Ffestiniog to Llandudno	39	52
Rhyl to Colwyn Bay	32	40
Newtown to Welshpool	19	20
Swansea to St. Davids	103	149
Haverfordwest to Wrexham	221	257
Pwllheli to Holyhead	81	107
Pwllheli to Llangollen	102	121
Cardigan to Brecon	119	134
Cardiff to Liverpool	205	224
Cardiff to Liverpool Airport	201	238
Cardiff to Aberystwyth	160	165
Coventry to Aberystwyth	168	196
Birmingham Airport to Swansea	154	199
Bristol to Caernarfon	244	284
Manchester Airport to Caernarfon	135	179
Aberystwyth to Caernarfon	103	114
Manchester Airport to Port Talbot	205	268
Manchester Airport to Liverpool Airport	45	52
Port Talbot to Liverpool Airport	224	258
Aberystwyth to Shrewsbury	102	116
Aberystwyth to Birmingham Airport	154	173

A regression analysis was conducted comparing raster and vector travel times for the routes in table 5.2. No constant term was fitted and the results were as shown in equation (5.2).

$$\underset{}{\text{VECTOR}} = \underset{(68.74)}{0.84}\ \text{RASTER} \tag{5.2}$$

R^2 (adj) = 97.2%

Figures in parentheses are t values.

where:

VECTOR = Calculated travel time (minutes) on vector network

RASTER = Calculated travel time (minutes) on raster grid

On the basis of the result given in equation (5.2), all the raster road speeds were multiplied by 1.190 (i.e. 1/0.84). Cells that did not have roads running through them (and therefore no impedance value) were assigned an impedance that assumed an average rural walking speed of 2.66 mph[16]. This value attempts to take into account the likely lack of suitable straightline footpaths between roads and the sample sites.

With the Welsh travel time zone algorithm defined, an actual versus predicted test of our arrivals function (as well as our revised methodology for calculating time zones) was possible[17]. The Forestry Commission only holds visitor data for five sites in Wales. In conversation with officials it became apparent that two of these were closed for unusually long periods during the year. Furthermore a third contained several special attractions not normally found at forest sites which raise visitor numbers above those normally expected for such a location[18]. Equation (5.3) simply relates actual visits per annum to the prediction obtained by applying our arrivals function to the time zones generated for these sites and using the sample period/annual visitor conversion factor calculated during the Thetford survey[19].

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[16]Equivalent to 4.29km/h or 1km every 14 minutes.
[17]Full details of this analysis are given in appendix 3.3.
[18]These include a museum, catering facilities and a variety of organised recreational activities.
[19]Prior analysis confirmed that any constant was insignificantly different from zero.

$$\text{ACTUAL} = \underset{(4.420)}{0.903\ \text{PREDICTED}} \qquad (5.3)$$

$$R^2 = 83.0\%$$

where:

ACTUAL = Actual arrivals at site (party visits pa.)
PREDICTED = Predicted arrivals at site (party visits pa.)

Equation (5.3) indicates that the arrivals function performs reasonably well, the slope coefficient for PREDICTED not being significantly different from 1. However, using dummy variables to account for the site-specific factors highlighted by Forestry Commission officials significantly improved the fit of this model, as shown by equation (5.4).

$$\text{ACTUAL} = \underset{(7.10)}{0.958\ \text{PREDICTED}} - \underset{(-2.23)}{73692\ \text{CLOSED}} + \underset{(2.70)}{107397\ \text{SPECIAL}} \qquad (5.4)$$

$$R^2 = 98.4\%$$

where:
CLOSED = 1 for two sites closed for extended periods during the year; 0 otherwise.
SPECIAL= 1 for one site with special attraction; 0 otherwise.

Clearly, the use of dummy variables with such a small number of observations is not ideal. However, given the reasonable strength of equation (5.3) we can conclude that the function does provide an adequate predictor of arrivals at a typical woodland site (although equation (5.4) illustrates the problems of applying the function to any particular non-typical site).

Given this result, the arrivals function can reasonably be applied to a regular grid of points to predict expected recreational visits to potential woodland sites across Wales[20]. An important practical issue, however, is the appropriate grid size for such an analysis. Even with

[20]Such estimates do not take into account the substitution effects which would arise in any specific area if a number of woodlands were planted in that locality. The object of the current exercise is to identify those areas where the establishment of a wood would be beneficial. The impact of supply side changes will be considered subsequently.

the use of a raster structure and other efforts to shorten processing, determination of travel time zones for a representative grid covering the entirety of Wales represented a significant computational exercise. Using a Sparc Sun1 workstation each site took between 15 and 30 minutes to process (depending on workload). Assuming the former time, calculation of a 1 km grid surface for the entire area of Wales (some 20,500 cells) would take over 200 days of continual processing. Even though three such machines were available for these calculations, a courser sampling scheme was clearly required.

The issue of grid size was investigated by defining two transects across Wales, one running east from the coast near Aberystwyth to the border, and the second running from a similar origin due south to a point just outside Swansea. Figure 5.4 illustrates these transects.

The horizontal transect consisted of 19 sites, the western-most 13 of which were separated by 2.5 km and the remainder at 5 km spacing. The vertical transect consisted of 18 sites all at a 5 km interval. Travel time zones were defined for all of these sites in the same manner as for the Thetford study. Zonal populations were then calculated and expected visits estimated using the arrivals function. Figures 5.5 and 5.6 illustrate predicted total annual visits for the horizontal and vertical transects respectively.

Examining the horizontal transect (figures 5.4 and 5.5) the overall pattern is highly encouraging. Sites 1 and 2, located at the western end of the transect, are close to the town of Machynlleth. This is reflected in relatively high predicted visitor numbers compared with neighbouring sites to the east which are located in the sparsely populated mid-western, Cambrian mountains. Poor infrastructure in the upland areas compounds the decline in predicted visitor numbers. The lowest numbers are estimated roughly midway between Machynlleth and Newtown, high in the mountains. Predicted arrivals rise sharply closer to Newtown, and the peak value is achieved at the site closest to the town. Thereafter visitor numbers stay high both because we are leaving the Cambrian uplands and entering more populous lowland areas, and because improved infrastructure means that English towns and cities, despite being relatively distant, now begin to have an impact upon predicted arrivals. The switch from 2.5 km to 5 km resolution is well illustrated by the jump in predicted arrivals between sites 13 (2.5 km resolution) and 14 (5 km resolution).

Figure 5.4: Location of two transects across Wales

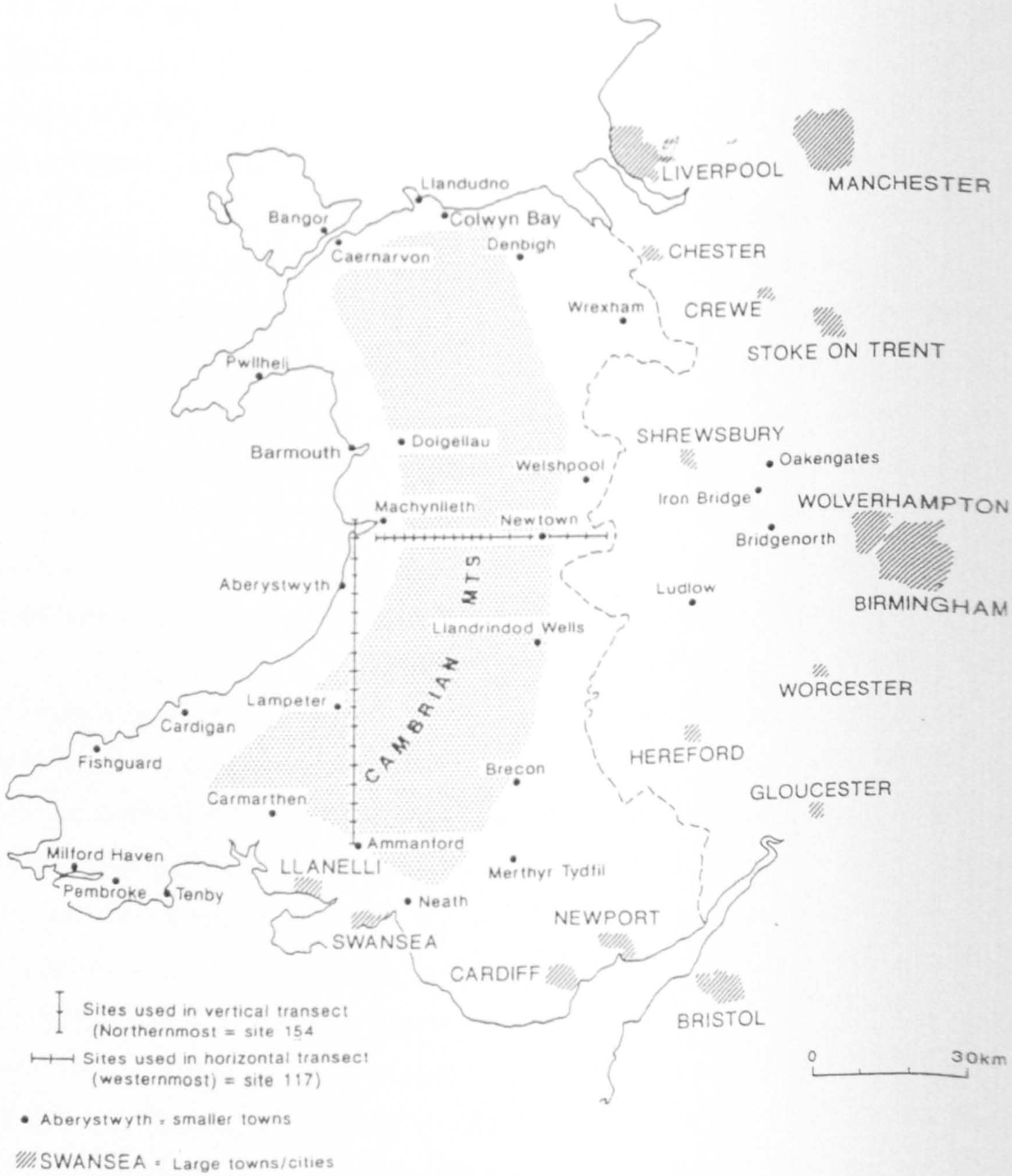


Figure 5.5: Predicted visits (parties per annum): horizontal transect

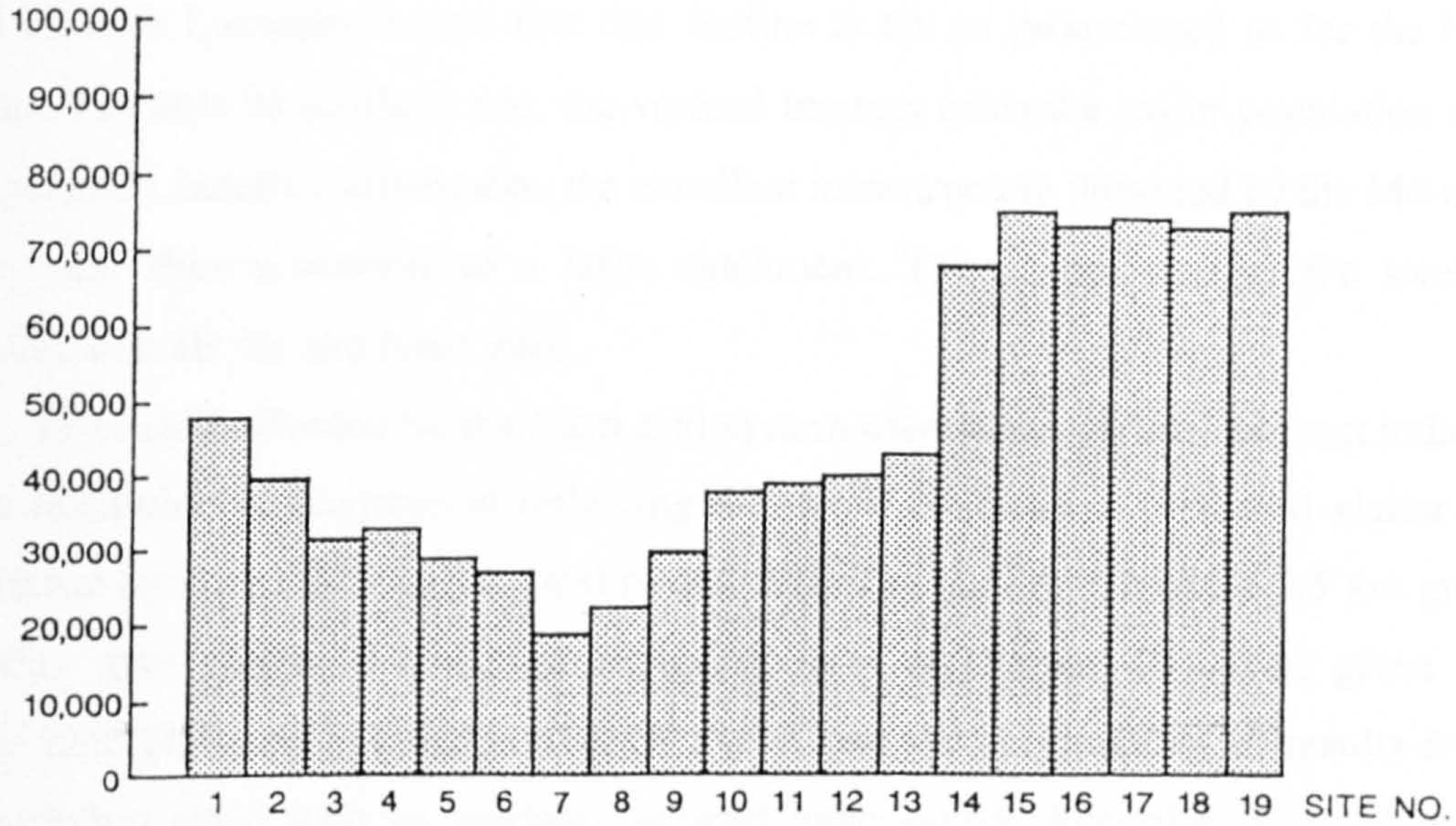
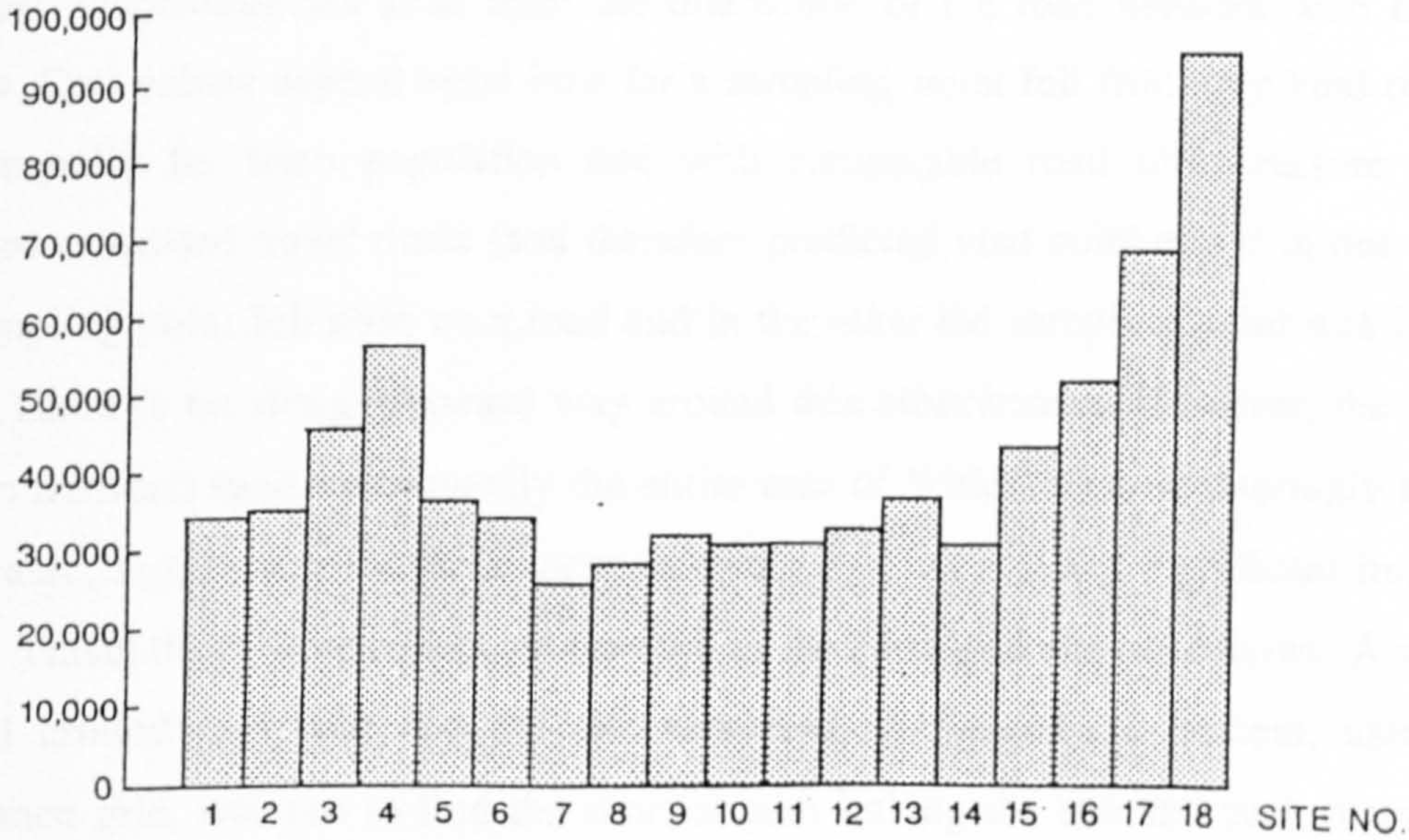


Figure 5.6: Predicted visits (parties per annum): vertical transect



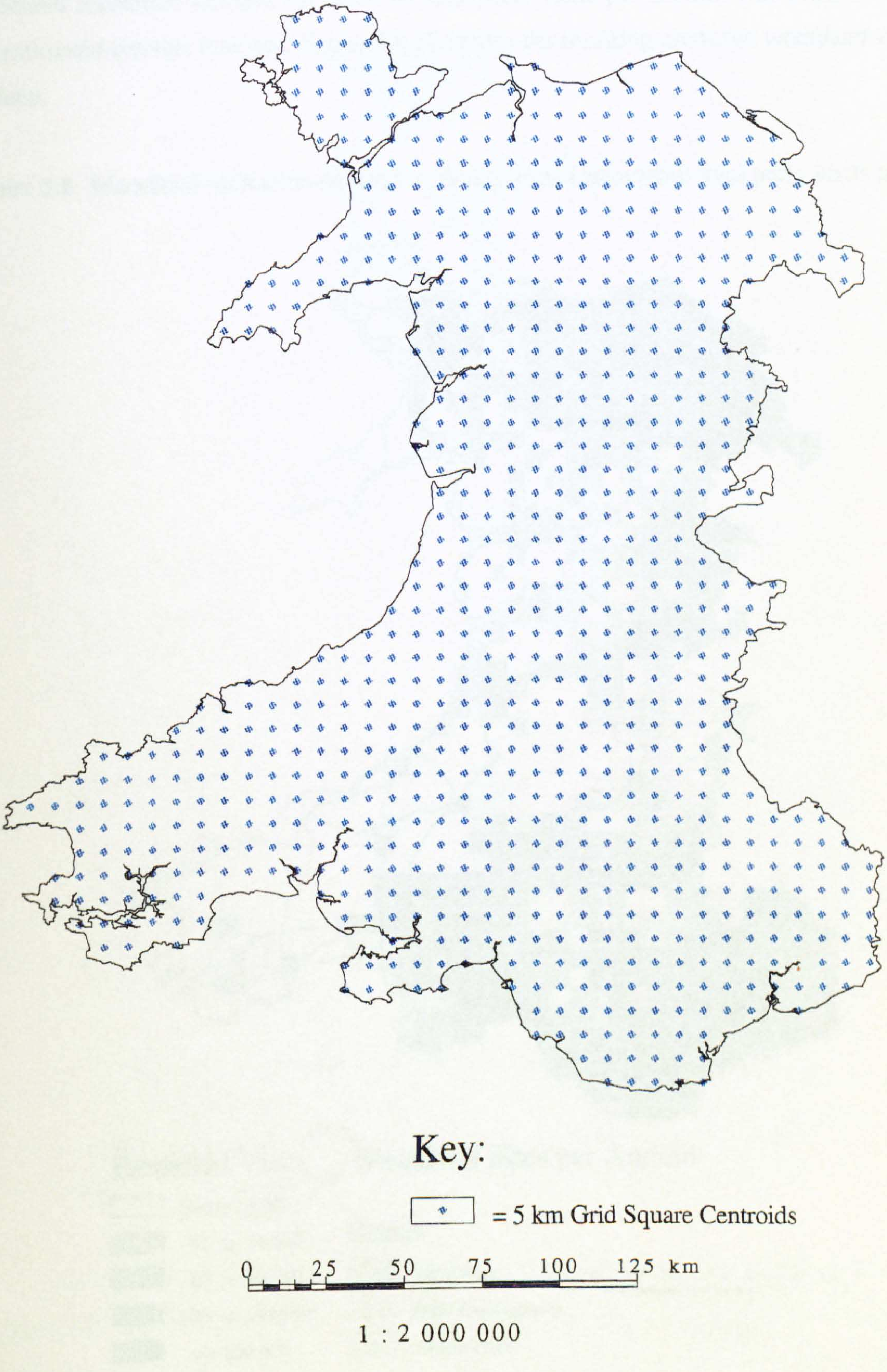
Findings from the vertical transect (figures 5.4 and 5.6) suggest that the 5 km grid does provide adequate sensitivity regarding changes in those factors determining visit numbers. The northernmost point lies in a relatively inaccessible, low population density area. However, moving southwards, the transect crosses an estuary and passes close to the town of Aberystwyth (site 4) and predicted arrivals rise accordingly. Thereafter the transect again climbs into the Cambrian Mountains resulting in a fall off of predicted visitors. However, towns such as Lampeter ensure that this decline is not as pronounced as for the horizontal transect. Towards its southern end, the vertical transect nears the major population centres of Swansea and Llanelli. Furthermore, the excellent infrastructure provided by the M4 motorway makes such sites accessible to a large catchment. This is reflected in the steep rise in predicted arrivals for the latter sites.

The detail afforded by the 5 km grid system used in the vertical transect indicates that such a resolution is adequate in reflecting the major contrasts in predicted visitor numbers engendered by population density and road availability/quality. Clearly a 2.5 km grid would inevitably give further information regarding rates of change. However, given the very considerable processing demands of such a grid, and the acceptability of results from the 5 km resolution sites, such an approach seemed unnecessary. Accordingly travel time zones were calculated for a 5km grid for the entirety of Wales. The base map of grid points used to generate subsequent visitor potential surfaces is illustrated in figure 5.7.

Regardless of the chosen resolution, certain sampling problems are difficult to alleviate. Inconsistencies arise from the interaction of the road network with the sampling pattern. Cell values depend upon how far a sampling point fell from any kind of road. Two areas equally far from population and with comparable road infrastructure might have different estimated travel times (and therefore predicted visit numbers) if in one of the areas the sampling point fell right on a road and in the other the sampling point was far from any roads. There is no straightforward way around this arbitrariness. However, the findings for the two transects (and subsequently the entire area of Wales) were reassuringly sensible and predictable, suggesting that these inconsistencies had not had any significant impact.

Travel times were calculated for each of the 5 km grid sites as follows. A window was defined around each site and the site rasterised. An allocation process, using the cost impedance grid, was run to find the shortest path linking the site and each other cell in the raster surface. The impedance necessary to reach each of these locations was then assigned to corresponding cells in an output grid. This provided, in minutes of travel, a time-surface output which was then classified into time zones. Information on total residents for each time zone were subsequently extracted from the rasterised population surface and recorded in a separate file. This process was then iterated across all sample sites in the 5 km grid.

Figure 5.7: 5km grid points used to generate the predicted woodland visitors surface.



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Once time zones and zonal populations had been calculated for all grid points, woodland recreation demand (in terms of total party visits per annum) was predicted using the estimated arrivals function. Figure 5.8 illustrates the resulting predicted woodland visitors surface.

Figure 5.8: Woodland recreation demand in Wales: Predicted annual total party visits per site

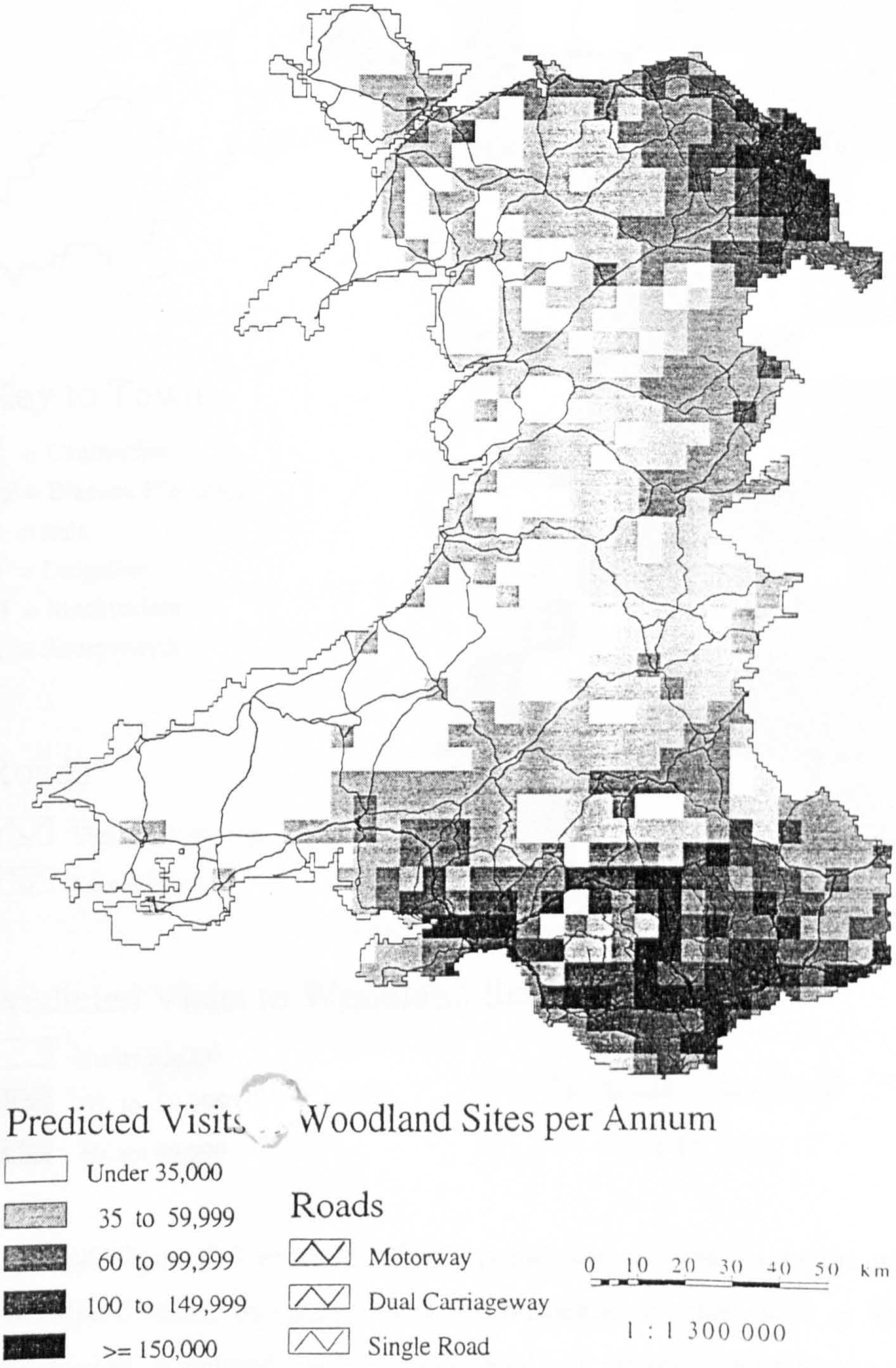
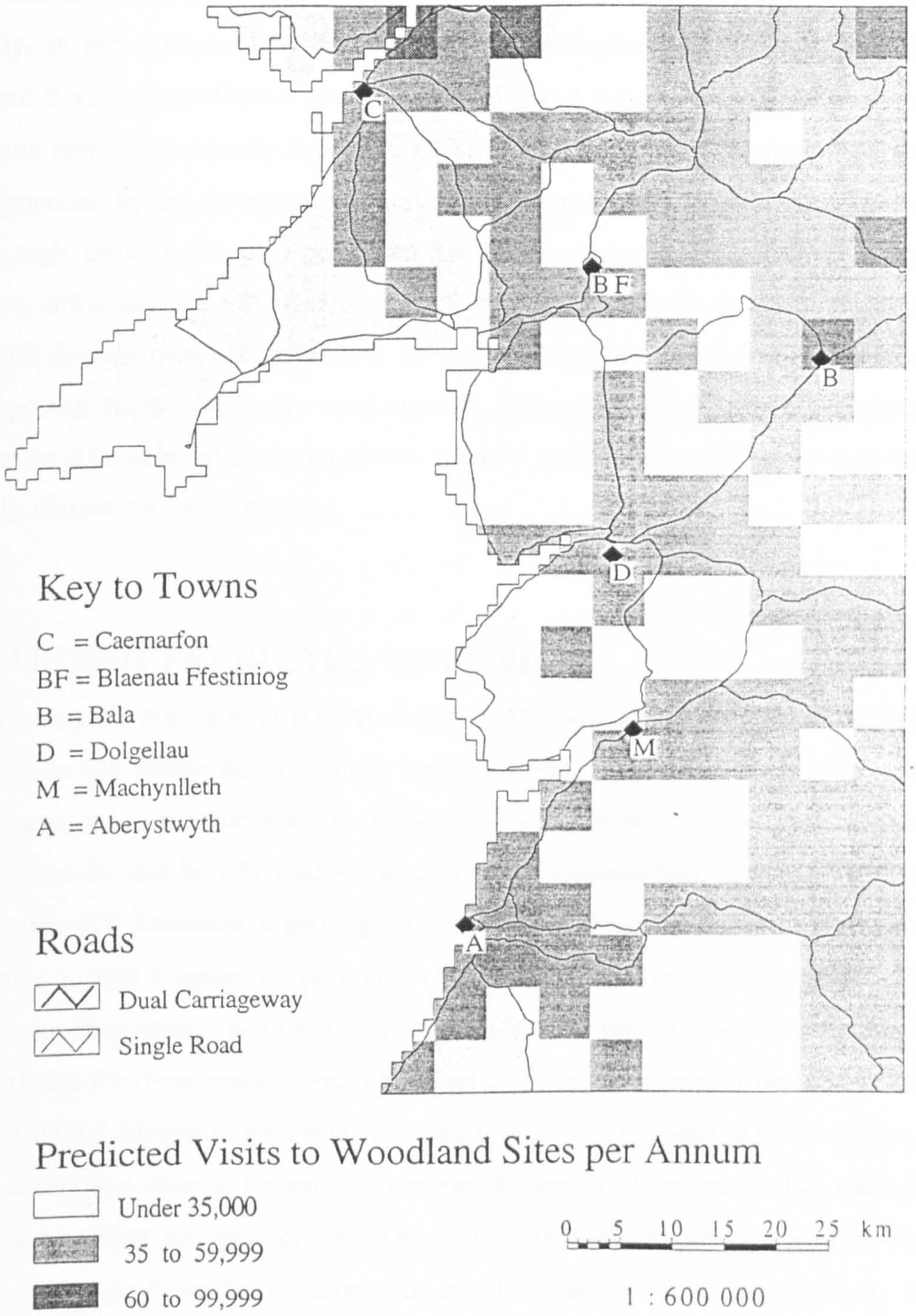


Figure 5.9: Woodland recreation demand in North Western Wales: Predicted annual total party visits per site



As expected, figure 5.8 strongly reflects population distribution in the prediction of recreational woodland visits. In south Wales the influence of cities such as Swansea and Cardiff and the densely populated 'valleys' area, results in relatively high visitor predictions.

As expected, figure 5.8 strongly reflects population distribution in the prediction of recreational woodland visits. In south Wales the influence of cities such as Swansea and Cardiff and the densely populated 'valleys' area, results in relatively high visitor predictions. Similarly, in the northeast, the influence of nearby English cities such as Manchester and Liverpool is very clear. Conversely, in mid Wales and western coastal areas, the sparsity of population results in severely depressed visitor arrival estimates. Population impacts tend to be compounded by the distribution of higher quality transport infrastructure. This inflates the already high arrivals numbers generated by the proximity of large centres of population. However, infrastructure effects are perhaps best demonstrated in areas of relatively low population density such as coastal, mid and north Wales. Figure 5.9 shows this area in detail, superimposing the relevant major road network. Here we can see that the presence of a major road creates a heightened potential visitor corridor as it facilitates visits by individuals from relatively distant travel time zones.

5.4: VALUING PREDICTED DEMAND

5.4.1: VALUING RECREATIONAL VISITS TO WOODLAND: SYNTHESIS

While the visitor demand maps are interesting, they are of limited use for decision making purposes as they do not tell us about the value of this demand and cannot therefore directly assist in cost-benefit analysis of forest management and planning. In chapter 3 we reviewed the UK literature regarding valuation of recreational visits to woodland. In our conclusions to that chapter we present a reworking of the Benson and Willis (1992) ZTC studies and a cross-study 'meta-analysis' of per-visit CV studies. Table 5.3 reports univariate WTP statistics for these results alongside those from our own studies detailed in chapter 4[21].

Table 5.3 illustrates a considerable range of values for woodland recreation, although it is noticeable that none of the estimates reported exceeds £5 per party visit, indicating some consensus regarding the appropriate range of valuation. Estimates produced by the CV are consistently below those from variants of the TC. This result is supported by the recent

[21]An alternative approach, reported on in appendix 3.4, is to adjust users WTP per annum by the number of visits per annum. However, such an approach raises the further issue of how respondents discount future visits when forming per annum or longer term WTP responses. We have shown elsewhere that such discounting may be very heavy (Bateman, et el., 1992) and may even be hyperbolic rather than exponential (Henderson and Bateman, 1995).

findings of Carson et al. (1996) who assess 83 studies providing 616 comparisons between CV and revealed preference (RP; mainly TC) estimates. They report a sample mean CV/RP ratio of 0.89[22]. These results are in themselves interesting as, in theory TC estimates consumer surplus while CV estimates total WTP (consumer surplus plus price paid), in other words we might expect the reverse relationship to hold. This problem is exacerbated when we consider that CV may also be capturing users option and non-use values. Reasons why the observed relationship may hold are explored in Bateman (1993). Here we argue that CV responses may apply to the on-site experience to the exclusion of the remainder of the whole trip experience such that travel and time costs are treated as sunk costs. Here the respondent is only considering the surplus over those sunk costs. In effect therefore expecting TC and CV results to be the same may be a category mistake, consideration of which justifies the observed relation of value estimates.

Our Thetford 2 CV design effects experiment seems to have shown how far CV estimates can be either inflated or deflated by various respecifications of the survey questionnaire. Adopting a sensitivity analysis approach we can take the upper and lower bound results from this study as our first CBA valuation estimates. As expected our cross-study analysis of CV experiments produces a value between these extremes and this is accordingly adopted as our central CV estimate. To complement these we use our adjusted values from the Benson and Willis (1992) study as a ZTC estimate of recreation value, and our GIS based ITC estimate from the Thetford 2 study[23]. Table 5.4 summarises the sensitivity range of woodland recreation values used in our wider CBA study (ordered by value).

[22] 95% confidence interval = (0.81 - 0.96); median = 0.75. A weighted dataset records a similar mean of 0.92 although this is no longer significantly different from 1.0.

[23] Although the ITCM estimate based on perceived journey duration provides a slightly better overall fit, the difference is highly marginal. Furthermore the former model produces consumer surplus estimates which are very similar to those of our adjusted Benson and Willis (1992) results. Accordingly we prefer to indulge our own interests in GIS-based techniques in the belief that future studies combining perceptions with GIS measures will produce even better models.

Table 5.3: Valuing recreational visits to woodland: a synthesis of studies

Study	Method	£/person /visit[1]	£/party/visit[2]		
			mean	upper 95% CI	lower 95% CI
Benson and Willis (1992) (adjusted as per Ch.3)	ZTC	1.48	4.52	4.85	4.22
Cross-study (meta analysis)	CV	0.60	1.82	1.95	1.69
Thetford 1 (low range payment card)	CV	1.21	3.69	3.96	3.44
Thetford 1 (high range payment card)	CV	1.55	4.73	5.07	4.41
Thetford 1 (OLS)	ITC	1.07	3.37	3.61	3.14
Wantage (WTP/visit study)	CV	0.82	2.50	2.68	2.33
Thetford 2 (WTP/visit, no preceeding questions)	CV	0.20	0.61	0.65	0.57
Thetford 2 (WTP/visit, after mental a/c question only)	CV	0.46	1.40	1.51	1.31
Thetford 2 (WTP/visit, after WTP pa. question only)	CV	0.45	1.37	1.47	1.28
Thetford 2 (WTP/visit after mental a/c and WTP pa questions)	CV	0.78	2.38	2.55	2.55
Thetford 2 (ML model: GIS based time and journey costs)	ITC	1.20	3.59	3.85	3.35
Thetford 2 (ML model: based on perceived duration)	ITC	1.47	4.42	4.74	4.12

Notes: n/a = not applicable.
1. Figures are best estimate means (1990 prices). Appendix A3.4 reports 95% CI's and alternative estimates based on WTP per annum studies.
2. Per party per visit measures were not explicitly reported in the following studies: Benson and Willis (1992); cross study CV meta-analysis; Thetford 1, Wantage and Thetford 2 CV studies. In these cases per party per visit estimates have been calculated from reported per person per visit measures using party composition statistics given in table 5.3A below (adults and children being treated equally in this analysis) rates. Such statistics were taken from the Thetford 2 survey as detailed in table 5.3A as follows.

Table 5.3A: Descriptive statistics for party size: Thetford 2 survey

Measure	Party size (no. of persons)
mean	3.0523
upper 95% CI	3.2726
lower 95% CI	2.8468

Note: All measures adjusted for skew by taking logarithms, calculating mean and t-intervals and then finding exponentials.

Table 5.4: Sensitivity analysis woodland recreation values (£/party/visit; 1990 prices).

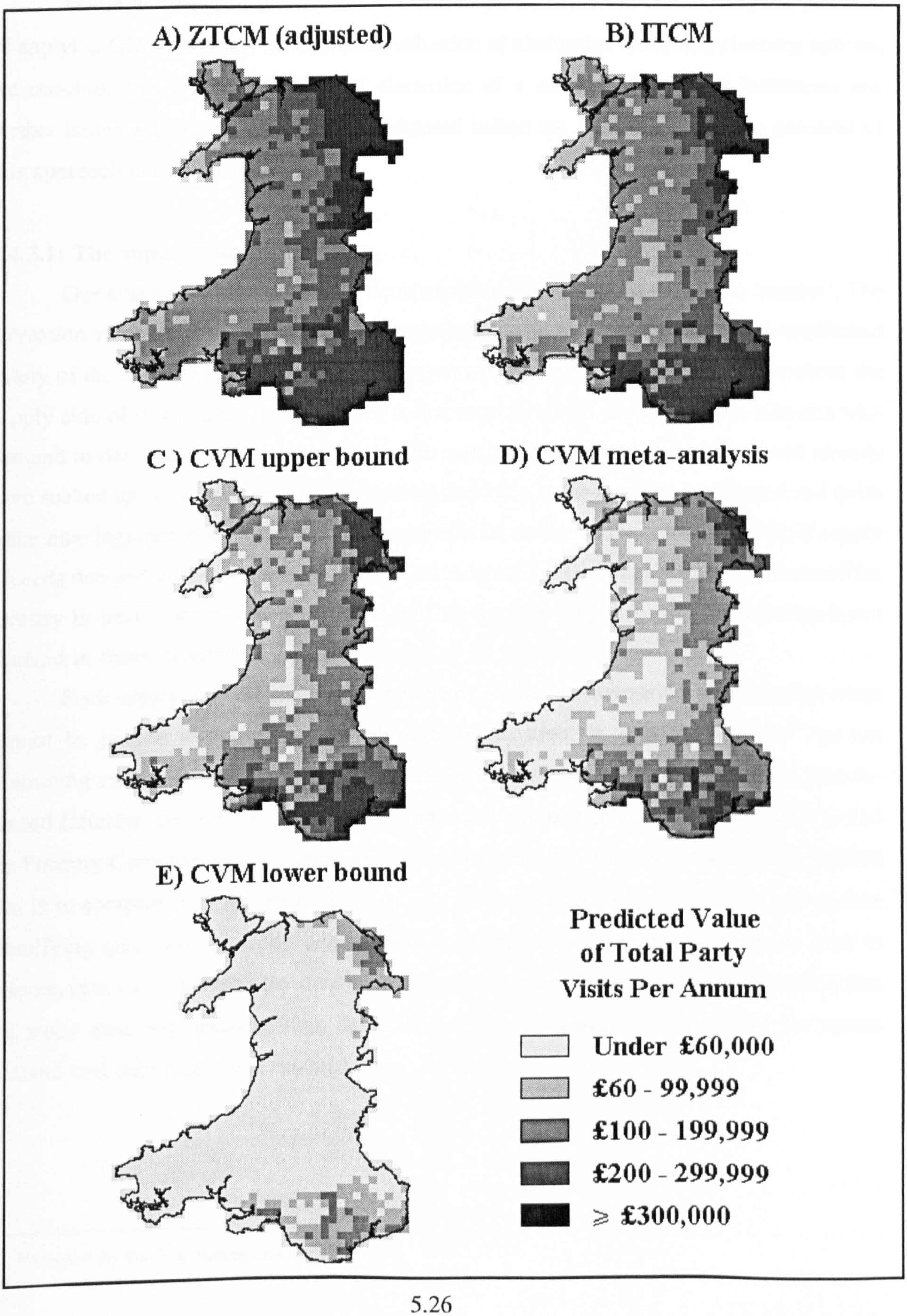
Study	Method	£/party/visit
Benson and Willis (1992): adjusted	ZTC	4.52
Thetford 2 (ML model: GIS based time and journey costs)	ITC	3.59
Thetford 2 (WTP/visit; after mental a/c and WTP pa. questions)	CV	2.38
Cross study CV meta-analysis	CV	1.82
Thetford 2 (WTP/visit; no prior questions)	CV	0.61

5.4.2: MAPPING PREDICTED RECREATION VALUES

The number of predicted party visits per annum (illustrated in figure 5.8) was simply transformed into a value of recreation demand by multiplication with the various party visit values given in table 5.4. This was achieved using the *scalar* command in the Idrisi GIS. Figure 5.10 illustrates the range of values produced by this exercise.

The distribution of values within each of the maps shown in figure 5.10 exactly mirrors that of the base demand map (figure 5.8) and is due to the same factors discussed previously. However, the wide variance in value estimates detailed in table 5.4 is graphically illustrated by figure 5.10. This is clearly a cause for some concern. While it may be that the 'envelope of valuation' (Bateman et al., 1992) described here is sufficient to justify certain decisions, the uncertainty of values illustrated shows that we should be very cautious regarding the interpretation of findings from any one study or even any one method. Such reservations are expanded upon below.

Figure 5.10: Predicted value of total annual recreation demand per site using five evaluation estimates



5.4.3: LIMITATIONS OF THE PREDICTED RECREATION VALUES

While we feel that the recreation value maps illustrate the methodological potential of applying GIS techniques to economic evaluation of alternative woodland planning options, we conclude this chapter with a brief discussion of a number of potential limitations and further issues which would have to be addressed before the full decisionmaking potential of this approach can be realised.

5.4.3.1: The supply side

Our analysis only considers the demand side of the woodland recreation 'market'. The recreation value maps tells us about the recreation demand for a typical woodland established at any of the 5km grid intersections of the base map (figure 5.7). It does not tell us about the supply side of this market. Their are two major ways in which the supply side interacts with demand to determine actual visits. Firstly, the existing distribution of woodland will already have soaked up some of our predicted demand. Secondly, as new forests are planted and (with some time lag) recreational services become available, so demand becomes satisfied. If supply exceeds demand in any one area such that non-congested excess supply exists, so demand for forestry in nearby areas will be diverted into the surplus supply forest thus reducing latent demand in those diverted areas.

Such supply induced substitution effects mean that our recreation demand value maps cannot be judged in isolation of supply side information. In ongoing research[24] we are examining various sources of such information including the Bartholomew database, remote-sensed (satellite) imagery, the Institute of Terrestrial Ecology (ITE) land cover database and the Forestry Commission's sub-compartment database and census of woodlands. Our eventual aim is to compare both the demand and supply side of the woodland recreation market thus identifying areas where surplus demand exists. In the absence of such analysis we have to assume, given an apparently reasonably uniform distribution of existing forest resources across the study area, that areas of high demand are likely to prove prime locations for excess demand and therefore forest establishment.

[24]Funded by English Nature and the ESRC.

5.4.3.2: Applicability of the Thetford Forest period to annual conversion factor

As part of our arrivals function calculations we had to convert from the survey period onto an annual basis. One concern here is whether the conversion factor used is valid for other sites or unique to Thetford Forest. In order to fully test this we would ideally need data regarding the annual distribution of visits both at Thetford and at any site we wish to extrapolate for. Unfortunately while such data exists for Thetford it is only currently being compiled for a few Welsh sites. Gillam (pers comm)[25] suggests that seasonality patterns are likely to be roughly similar across England and Wales and only differ in very remote areas such as the North of Scotland where seasonal peaks are likely to be relatively more pronounced. On the basis of this information, and in the absence of any contrary evidence, we feel that we have adopted a defensible approach to this issue[26].

5.4.3.3: Comparability of recreation in Thetford Forest with that in Wales

The major demographic and infrastructure differences which separate Wales from our East Anglian survey site are explicitly accounted for in out arrivals function which takes account of both population density and distribution and road quality and distribution. Two remaining issues are pertinent here. Firstly, does our survey site provide similar recreational services to those of our visitor potential map. By definition, the answer here is yes, because we are looking at the creation of similar service sites wherein the major recreational attraction is open access walking and it's associated activities. Analyses such as that given in equation (5.4) underline the differences in arrival rate which may occur at non-standard woodland sites. Secondly, does the psychological perception of woodland recreation differ between East Anglia and Wales? In considering this we must separate this out from the supply side problem commented upon above. Once this distinction is made we see no reason why such a perceptual difference should occur. Although we did not assess such issues, we have no reason to suspect any problem here, an assertion reinforced by the earlier work of Colenutt and Sidaway (1973) in the Forest of Dean which reports similar visitation patterns to those

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[25]Letter (9th August, 1993) from Simon Gillam, Chief Statistician, Forestry Commission. This letter also supported the use of the Thetford Forest data for estimating the arrivals function as this was stated to be amongst the most reliable available. The Forestry Commission undertook a UK Day Visit Survey during April to September of 1992 and 1993. However, such information was not available at the time of writing.

[26]One ad hoc solution to this problem might be to conduct a sensitivity analysis to assess the responsiveness of predictions to our assemptions.

observed in our own analyses.

5.4.3.4: Limitations of the predicted recreation values: conclusions

In conclusion, we recognise that our study concentrates exclusively upon the demand side and that supply side issues need to be considered if planning decisions are to be optimal. Ongoing work is addressing this issue. However, we see no further problems with the application of our arrivals function to the prediction of recreation arrivals in Wales and our predicted versus actual test suggests that this provides defensible estimates. The valuation of such demand raises further issues which we have considered briefly here and at length in previous chapters. Because of uncertainties surrounding the valuation issue, we have adopted a sensitivity analysis approach, producing a number of alternative demand value maps. In future chapters we augment these with further forest values before comparison of aggregate values with those from conventional agriculture in the study area.

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Chapter 6: Timber Valuation

6.1: INTRODUCTION

In this chapter we assess both the social and private (farmers') value of timber production. One of the most important influences upon the outcome of such analyses is the real price of timber. Because plantation returns are long delayed, any (even small) increase in real prices will have a major impact upon NPV sums. In order to assess this, the chapter opens with a brief history of commercial forestry in the UK designed to acquaint the reader with the recent, major and trend breaking increase in domestic timber supply (section 6.2). In the subsequent section (6.3) both the supply and demand sides of the UK market are modelled so that a balanced view on future prices can be drawn. These conclusions are reinforced by time-series analyses of price movements.

Whilst timber value is clearly important, private planting decisions are often determined by the availability of shorter term grants rather than long delayed felling benefits. In section 6.4 we review the various subsidies schemes available. Section 6.5 brings together the preceding discussions regarding prices and grants, with information regarding plantation costs and tree growth to produce the base rotation[1] models upon which our timber valuations are calculated.

The long time horizons inherent in woodland investments brings us to the vexed question of discounting. Section 6.6 discusses the principle of discounting and provides a brief review of the literature regarding the 'correct' discount rate with respect to both social CBA and private investment appraisal. We conclude that, as no single, clearly correct discount rate (or even method of discounting) can be identified, so a sensitivity analysis approach is called for.

Section 6.7 provides investment appraisal results from the viewpoint of a private individual (the farmer) while section 6.8 extends this to provide a limited social CBA of the timber product of a plantation (i.e. ignoring those externalities dealt with elsewhere in this research). In both cases NPV and annuity equivalent results are reported, the former being the usual fare of the forest economist while the latter being comparable with competing agricultural outputs.

[1]A rotation is the full lifespan of a plantation from planting to felling.

When commencing this analysis it soon became clear that assessment of all possible woodland tree species was not feasible because of both time constraints and lack of data concerning less popular species. Furthermore, preliminary analysis indicated that costs and benefits of different conifers would be reasonably similar[2], the same being (broadly) true of broadleaves. Therefore, two 'indicator' species were selected for analysis: Sitka spruce (conifer), and beech (broadleaf).

6.2: HISTORICAL BACKGROUND

6.2.1: PRE-1945

In terms of land use, British forestry has always been the poor cousin of agriculture. Although the prehistoric 'natural' condition of the land was primarily as forest, the influence of man has consistently been to clear-fell and convert the land to agricultural use. Even by the time of the Domesday Book only 15% of England remained under trees[3]. This downward spiral continued for most of the last millennium with particularly heavy losses occurring in the sixteenth and seventeenth century when adoption of advanced husbandry techniques and subsequent enclosure of common land allowed agriculture to confine forestry to marginal areas and private parklands, the latter often being operated on a non-commercial basis for private amenity values (Rackham, 1976). By 1900 only 4% of England and Wales and 2% of Scotland and Ireland was under forestry, these being by far the lowest levels in Europe (ibid).

By the start of the twentieth century the UK was almost completely dependent upon imports for its timber supply. This strategic weakness was exposed by the German naval blockade of Britain during the First World War. With timber a major input to the UK's vital coal industry it was felt that the creation of a strategic domestic timber supply was essential to the future security of the country and, in 1919, the Forestry Commission (FC) was established[4]. Although strategic security of supply constituted the FC's initial objective this was quickly supplemented by further aims such as the commercial production of timber; the stimulation of employment in areas of rural depopulation; and the provision of public benefits

[2]This is of course a relative statement. Differences do exist and are important at the micro level. However the magnitudes of costs and benefits are similar enough for this to be a defensible assumption for the purposes of this study.

[3]Pers. comm. Colin Price, Dept of Agricultural and Forest Sciences, UCNW, Bangor.

[4]The decision to establish the Commission was approved in 1918.

such as open-access recreation and wildlife habitat[5] (Bateman, 1992).

Public sector forestry in the UK has from the outset followed an erratic course. A strong initial political will to establish a secure national timber supply ensured that the 1920s were a period of major afforestation, reversing the trend (if not the effects) of the previous millennia. However, as memories of wartime shortages receded and world timber prices slumped, the 1930s saw planting figures fall well behind the 30,000 ha annual target envisaged at the creation of the FC. This slump was offset to some extent by the Commission's own promotion of forestry as a response to rural depopulation trends and a Government initiative "to create a settled force of woodsmen and their families whose livelihood would be enhanced from their own tenanted smallholdings" (Philip, 1976). Nevertheless the 1930s still saw an overall contraction of new planting.

6.2.2: POST-1945

Figure 6.1 illustrates total, FC and private sector annual planting from 1945 to the present day.

6.2.2.1: Public sector forestry

The end of the Second World War marked the start of the most sustained period of UK forestry expansion in recorded history (see figure 6.1). Initially, national security concerns and high prices again highlighted strategic policy objectives. The post-war adoption of a planned approach to the economy, firm prices and the expansion of the world timber trade ensured that FC planting accelerated to a peak of over 28,000 ha per annum in the decade following the war. The period from the mid 1950s to the early 1970s was characterised by fairly stable public sector planting at about 24,000 ha annually. This was helped by a Government decision to allow the FC to operate at a favourably low rate of return compared to other state investments. A discount rate of only 3%[6] was required of the Commission compared to rates of between 5% and 10% for other State owned enterprises[7].

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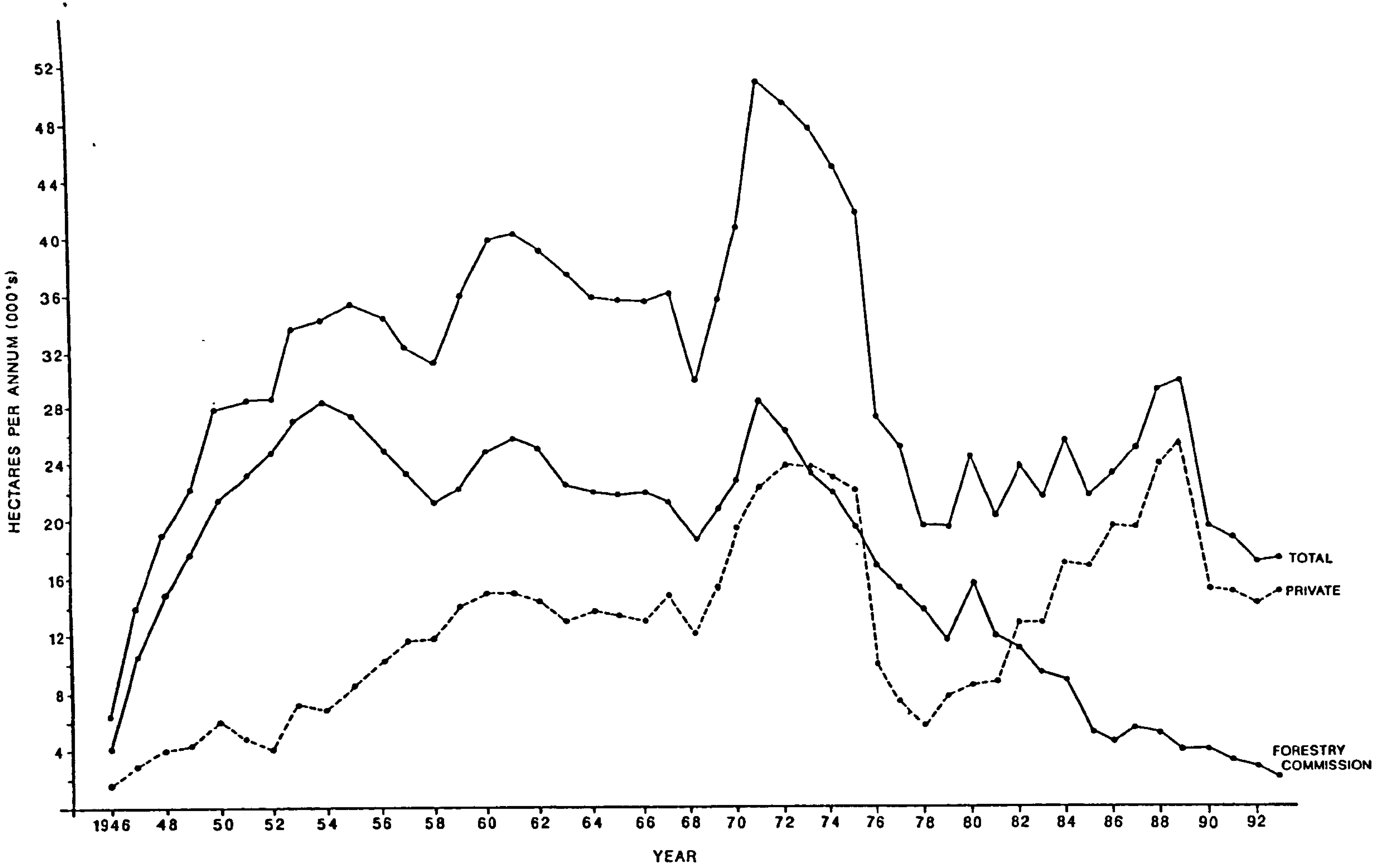
[5]In recent years the FC has also defended its existence as a source of import savings and reduction in agricultural subsidy. Bateman (1992) shows the import substitution argument to be invalid.

[6]Even lower rates of return were required from plantings carried out in Northern Ireland. From 1989 the FC was set a target rate of return of 6% but, as this is virtually unattainable without explicit valuation of non-market benefits, the Treasury allowed new investment decisions to be taken at a 3% rate with the resultant shortfall being written off as Forestry Subsidy (H.M. Treasury, 1991; Annex G). Felling decisions remain at a 5% d.r. to retain compatibility with existing FC appraisal systems (Adrian Whiteman, pers. comm. October, 1994).

[7]From 1989 this has been set at 8% for commercial public sector enterprises with a discretionary rate of 6% applied to projects with significant non-market benefits (H.M. Treasury, 1991).

Figure 6.1: Forestry Commission, private sector and total annual forestry planting: Great Britain 1945-93 ('000 ha per annum)



Source: Forestry Commission (1979,1985a,1988a,1989,1990,1993,1994a)

1971 marked a significant peak for the FC with plantings exceeding 28,000 ha p.a. for the first time since the early 1950s. However, that year also marked a turning point in the fortunes of UK public sector forestry, beginning a downward trend in planting which continues over two decades to the present day. The 1970s were a difficult period for the UK economy with the oil crisis and domestic economic problems (in particular relatively high inflation and poor trade balances) leading to heavily depressed growth rates. This put pressure on all areas of public finance to which the FC was not immune. Contractions in FC employment (Thompson, 1990) accompanied reductions in planting and by 1979 annual planting had dropped to 11,800 ha p.a., i.e. roughly 40% of the 1971 level.

The election in 1979 of a Conservative government, pledged to the reduction of the public sector in favour of private enterprise, meant that the decline in new planting seen in the 1970s has been extended throughout the 1980s and up to the present day. By 1993, annual planting had fallen to less than one-tenth of the 1971 peak. However, a more serious threat to the absolute scale of FC operations arose in 1981 when an extensive programme of land sales was implemented[8]. In the following year and for the first time since its creation, the FC was forced to sell more land than it purchased. Since that date the overall extent of the FC estate has consistently fallen. Between 1981 and 1994 over 150,000 ha of FC land were sold to the private sector, of which 80,000 ha was under forest. In the light of the government's recent failure, in its 1993/94 review of the Commission, to privatise the FC estate at one stroke[9], it is notable that the disposals programme has been noticeably stepped up as a method of facilitating 'privatisation by the back door'. Table 6.1 details FC land holdings throughout the period of the disposals programme. Despite numerous ministerial pronouncements on safeguarding public access to land sold by the FC privatisation has in almost all cases led to the exclusion of the public[10] (Goodwin, 1995). This is particularly serious given that it has been in areas of high population where the proportion of FC woodlands privatised has been highest[11] (Lean, 1996).

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[8]See statement by the Secretary of State reproduced in Appendix V of FC (1985b).

[9]During 1993/94 the government considered a variety of proposals for the future of the FC. National opposition to the prospect of privatisation apparently made such a policy untenable (at least in the short term).

[10]In the period from October 1991 to November 1995 of 35,233 ha privatised only 506 ha (1.4%) has had freedom of access guaranteed (Goodwin, 1995).

[11]For example, between 1981 and 1996, 91% of FC woodlands in West Yorkshire were privatised; 72% in Durham; 67% in Kent; 53% in Humberside and 43% in Essex (Lean, 1996). However, one countervailing trend has been the growth of charity funded woodlands (although these are not always open-access) such as those operated by the Woodland Trust, which was recently awarded £6 million by the Millennium Commission for its Woods on your Doorstep scheme (Smith, 1996).

6.2.2.2: Private sector forestry

From the outset, direct Government intervention through the agency of a State forestry service has been complemented by the stimulation of a private forestry sector via the provision of tax relief and other incentives to private individuals who invest in timber production[12].

Table 6.1: Forestry Commission holdings: Great Britain 1978-96 ('000 ha)

YEAR	FC PLANTATION		AWAITING PLANTING	SCRUB etc	TOTAL FOREST	TOTAL FC LAND[1]
1978	862.5		83.4		945.9	1,253.2
1979	868.2		77.0	7.0	952.2	1,256.3
1980	884.0		71.5	6.9	962.4	1,263.4
1981	895.7		63.1	7.1	965.9	1,264.0
1982	905.5		51.5	7.9	954.9	1,258.7
1983	908.7		46.1	7.9	962.7	1,250.9
1984	901.7		39.3	8.3	949.3	1,209.2
1985[2]						
1986[2]						
1987	899.7		23.4		926.4	1,156.4
1988	898.5		20.6		919.1	1,149.4
1989	898.2		17.2		915.4	1,144.2
	PRODUCTIVE	OTHER[3]				
1990	863.5	34.3	11.2		909.0	1,139.5
1991	858.5	34.5	9.8		902.8	1,133.1
1992	855.3	34.8	5.6		895.8	1,127.5
1993	845.4	37.1	5.1		887.6	1,115.4
1994	826.6	44.0	3.2		873.8	1,099.5
1996[4]	n/a	n/a	n/a		n/a	1,082.8

Notes: 1 = Total forest + Nursery land + Agricultural land + Unplantable + Forestry workers holdings
2 = Not available at time of compilation
3 = Recreational land, etc.
4 = Not from official statistics

Source: Forestry Commission (1979,1985a,1989,1990,1993,1994a); Lean (1996)

[12]Details of these tax relief schemes are given in Bateman (1992).

Despite these incentives, inexperience meant that initial private sector involvement was very restrained. However, from the late 1950s a proliferation of firms specialising in facilitating private forestry investments considerably eased the practical problems of such investment. These companies located land, arranged purchases, planting and felling, and took care of the tax liability and refunding formalities thus allowing those for whom tax relief was an attractive proposition to become forestry owners without ever having to visit a plantation or see a tree.

In this way post-war planting of private woodlands expanded at a consistently increasing rate from 1945 to the early 1970s (see figure 6.1). However, as with the FC, the 1970s were a period of relative decline for the private forestry sector. As the OPEC oil-shock sent the world economy into recession, so the UK's forest owning elite no longer had the excess taxable income to divert into forest tax-havens. However, these were just the people who benefitted from the Thatcherite private sector boom of the 1980's and by 1989 the planting of private woodlands was at its highest ever level. In the search for cheap afforestable land[13] many sites of great ecological value were destroyed (RSPB, 1987). This factor, and a national outcry against such tax-avoidance[14], caused the government to act and withdraw such tax-relief[15].

The scrapping of tax-relief had an immediate impact upon private sector planting which almost halved between 1989-90. The reason it did not fall further was primarily due to a system of various planting and maintenance subsidies (discussed subsequently) designed to appeal to farmers and landowners rather than those in search of tax-havens. These appear to have generated a reasonably constant annual expansion in private woodland of the order of approximately 15,000 ha per annum throughout the period 1990-94.

6.2.3: HISTORICAL BACKGROUND: SUMMARY

In forestry terms the UK has only recently expanded its domestic supply. Although it grew rapidly in the post-war period, the FC now appears to be contracting rapidly and the

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[13]Unlike most other planting costs, land purchase was not tax deductible. This led investors to plant on cheap but often highly unsuitable, wetland areas, destroying valuable natural habitats to produce very poor but highly tax-deductible plantations (RSPB, 1987).

[14]Culminating in a disparaging Observer front page magazine feature on the 100 largest forest owners in Britain (Lean and Rosie, 1988). See also The Times (1988) and Bloom (1988).

[15]Announced in the Chancellor's 1988 budget statement (UK Parliament, 1988) but not coming into effect until late 1989.

degree to which this is offset by increases in private woodland is uncertain. However, the potential for expansion is clear. After 75 years of growth only 10.3%[16] of the land area of Great Britain is under woodland while 77% is under agriculture. This compares with EC averages of 25% and 60% respectively (FICGB, 1992). Given ongoing and planned contractions in the CAP, we therefore conclude that there may be scope for continued expansion of domestic timber supply although this is clearly going to be subject to government policy (both with regard to direct intervention and subsidies) and long term market conditions. It is to the latter subject that we now turn.

6.3: THE UK TIMBER MARKET AND LONG TERM PRICES

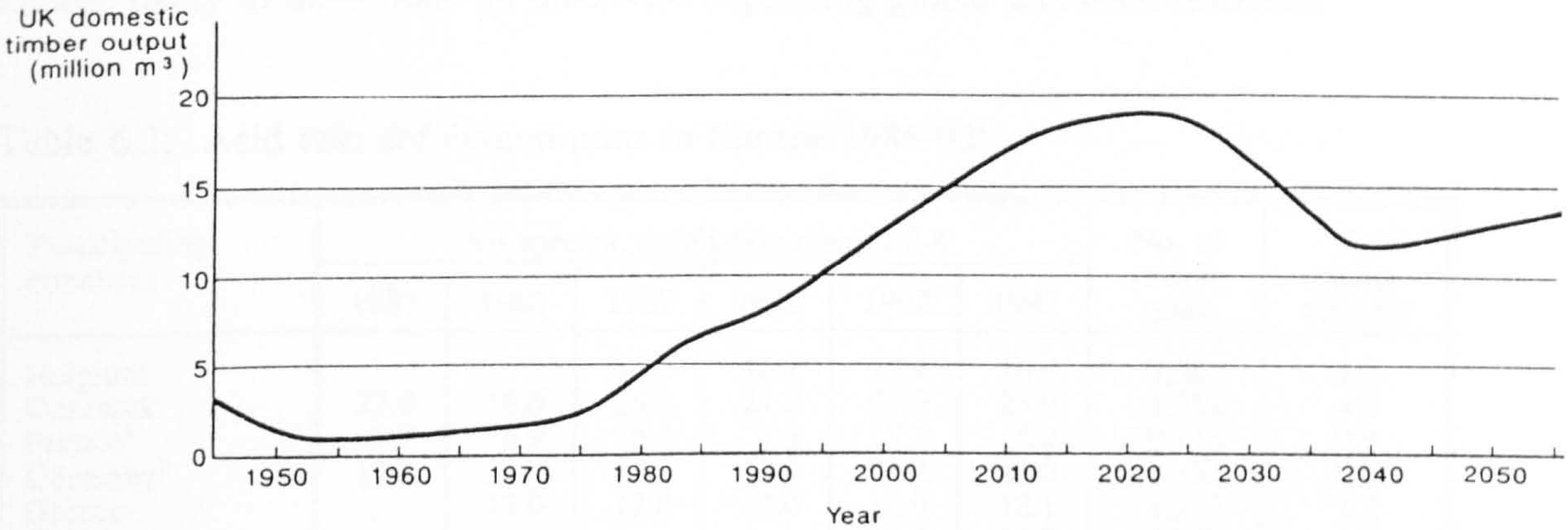
6.3.1: SOFTWOODS

At present the UK consumes some 53 million m^3 of timber[17] annually of which nearly 44 million m^3 (83%) is softwood based (FICGB, 1992). In comparison UK timber production (all species) currently stands at some 6.7 million m^3 per annum with a further 8.2 million m^3 of recycled fibre production (ibid). This very considerable difference between domestic demand and supply results in timber being the fourth largest UK import category at a value of £6.3 billion in 1991 (ibid). With domestic demand forecast to double in the next 60 years (ibid) and concern rising regarding acid-rain damage to softwood timber stocks (Bergen et al, 1992), some commentators (the 'pro-forestry school'; Doran, 1979) have forecast increases in future real prices for timber. However, we see two major flaws in the supply aspect of this argument. Firstly, the present level of UK production represents only the early stages of an ongoing dramatic expansion of domestic supply engendered by the sustained high levels of planting in the inter-war years and the period from the late 1940's to 1970's. This is set to continue well into the next century reaching an estimated peak of nearly 20 million m^3 by the early 2020's tailing off (as a result of the curtailing of FC planting in the past two decades) to a plateau of about 12 million m^3 by the middle of the next century (see figure 6.2). Secondly, and more importantly, this expansion of domestic supply has been echoed by an increase in the availability of softwood import supplies[18].

[16]This decomposes into 14.7% in Scotland, 12.0% in Wales and 7.4% in England (FICGB, 1992).
[17]Measured in wood raw material equivalent (WRME).
[18]This trend is exemplified by the case of Sweden where, since the 1930's, timber growth has consistently outstripped cutting (Wibe, 1992).

World coniferous roundwood production rose from 1096 million m^3 in 1971[19] to a peak of 1307 million m^3 in 1986 slipping back only slightly to a level of 1295 million m^3 in 1991 (Whiteman, 1995). When combined with arguments regarding ongoing technical change[20], these factors seem to suggest that real prices for softwood are unlikely to increase in the foreseeable future.

Figure 6.2: Actual and predicted UK domestic production of sawn softwood 1945-2055



Sources: Timber Trade Federation (1987); Bateman and Mellor (1990); FICGB (1992).

Such an argument would be invalid if the observed increase in world supply were based upon non-sustainable exploitation of existing stocks. However, while the total extent of global forest land has decreased alarmingly since WWII (see subsequent discussions), forest stocks in the major conifer growing countries[21] have increased from 1593 million ha in 1971 to 1648 million ha in 1991 (Whiteman, 1995)[22].

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[19]These measurements are in underbark volumes.

[20]Two forms of technical change can be identified (Bateman, 1988a): (i) improved plantation husbandry; (ii) increased availability of timber substitutes (particularly in the construction industry, see Leigh and Randell, 1981).

[21]Former USSR, Canada, USA, Sweden, Finland and Norway.

[22]This argument uses a simple definition of sustainability, namely that overall resource size should be non-declining. However, it may be that the conifer plantations underpinning these statistics are degrading the natural environments in which they are grown. This is an important issue but introduces a further level of complexity which we were unable to address within this research.

Concerns about acid-rain initially appear to be better founded. Table 6.2 details rates of European defoliation arising from acid-rain, showing that this is particularly serious in the UK[23].

While the defoliation problem appears widespread there have been few studies of its economic impact. Ewers et al. (1986) estimate a net present value[24] of expected future damages to German forests of DM 1.2-1.5 billion (roughly £500 million) for the period from 1983 to 2060. However, when compared to a present softwood production value of over £10 billion *annually* from the six largest producers alone (Whiteman, 1995) such damages do not appear likely to undermine an otherwise expanding global softwood resource.

Table 6.2: Acid rain defoliation rates in Europe 1986-92[1]

Participating countries	All species, defoliation classes 2-4						No. of sample trees	% change 1991/92
	1987	1988	1989	1990	1992	1992		
Belgium			14.6	16.2	17.9	16.9	2,384	-1.0
Denmark	23.0	18.0	26.0	21.2	29.9	25.9	1,558	-4.0
France[2]	9.7	6.9	5.6	7.3	7.1	8.0	10,113	0.9
Germany[3]	17.3	14.9	15.9	15.9	25.2	26.0	103,422	0.8
Greece		17.0	12.0	12.0	16.9	18.1	1,912	1.2
Italy					16.4	18.2	5,857	1.8
Luxembourg	7.9	10.3	12.3	12.3	20.8	20.4	1,152	-0.4
Netherlands	21.4	18.3	16.1	16.1	17.2	24.5	32,875	7.3
Portugal		1.3	9.1	9.1	29.6	22.5	4,518	-7.1
Spain		7.0	3.3	3.3	7.3	12.3	11,088	5.0
United Kingdom	22.0	25.0	28.0	28.0	56.7	58.3	8,856	1.6

Notes:

1. Percentages of trees surveyed in defoliation classes 2-4: damage classes ranging from moderate to severe
2. Change in sampling procedure in 1988
3. 1986-90 only includes Western Germany

Source: Pearce (1993) adapted from ECE (1993)

Given these factors, significant increases in real softwood prices seem, a-priori, unlikely. Indeed the possibility of decreasing real prices does not seem unfeasible. We therefore formulated a null hypothesis of constant real prices which we tested in two ways:

[23]Note that up until 1993/94 the UK system of defoliation classification differed from that used in Europe. The recent adoption of the EC classification by the FC has significantly reduced the apparent UK defoliation rate. However, even using the old system (which the FC retains alongside the EC approach) defoliation of several important species declined during 1993/94 (FC, 1994b).

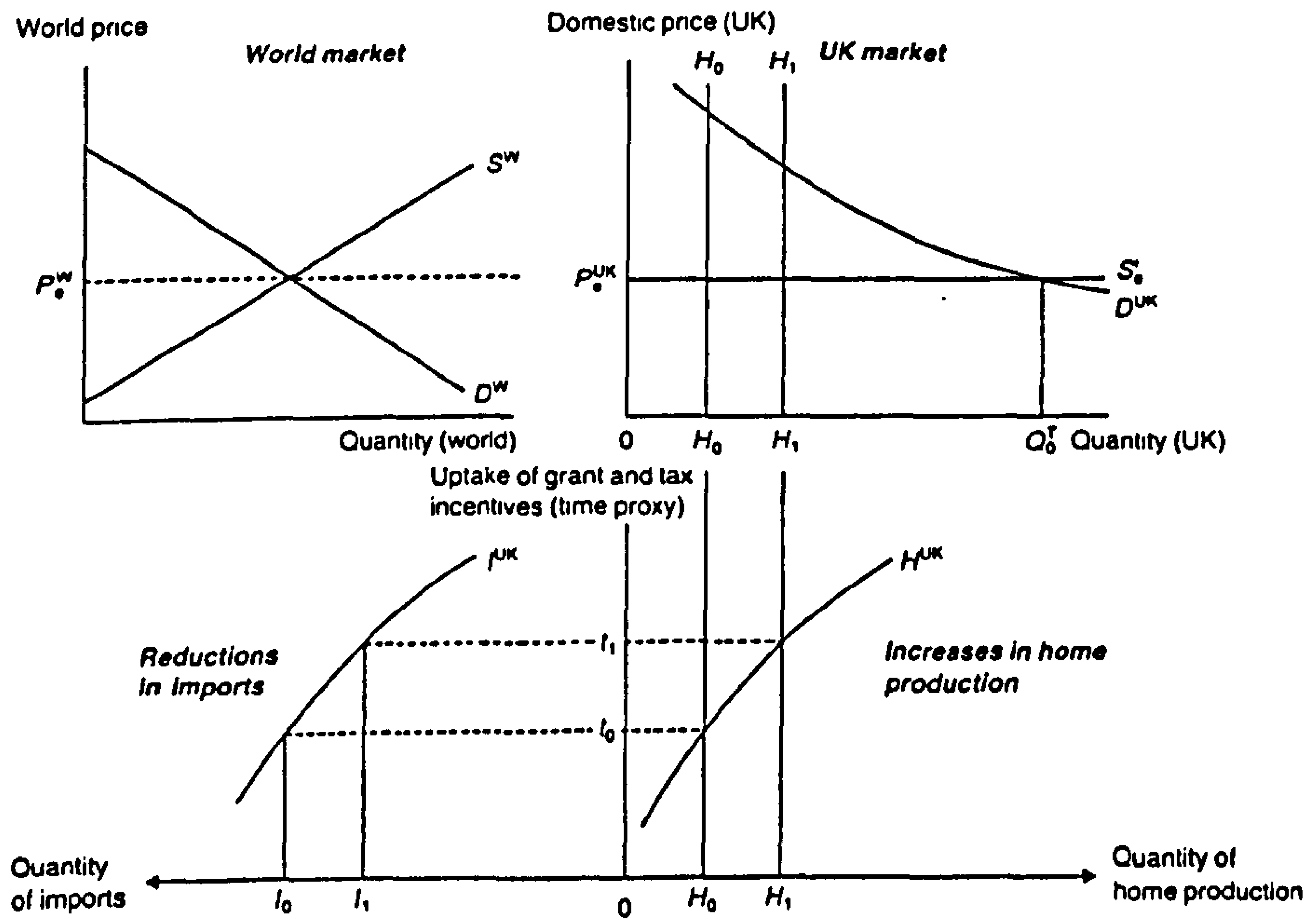
[24]Using a real discount rate of 2%.

firstly, an econometric model of the UK softwood market was constructed and investigated; secondly, a time-series analysis of real price trends was conducted.

6.3.1.1: An econometric model of the UK softwood market

Models of UK demand, domestic supply and imports were formulated from data for the period 1946-86 (full details of this analysis are provided in appendix 4.1). These showed that prices were linked directly to the world market rather than to domestic supply which formed a minor part of overall consumption. As domestic supply has increased it has progressively substituted for imports[25] as illustrated in figure 6.3.

Figure 6.3: The UK timber market: impact of increases in domestic supply



Source: Bateman and Mellor (1990)

A statistical investigation of this model showed that it fitted the data well but that no significant link between supply and prices could be found (details in appendix 4.1). Our

[25]Bateman (1992) shows that if non-market benefits are excluded this intervention-induced import substitution appears to constitute a market failure. However, it is argued that the inclusion of non-market benefits reverses this result.

timber market analysis therefore fails to find any empirical (or strong theoretical) support for increasing real prices[26].

6.3.1.2: Time series analysis of softwood prices

A number of time series analyses were carried out to test whether real prices were increasing or not (full details of these analyses are given in appendix 4.2). Inspection of long-run price indices[27] suggested that real prices had remained relatively stable during the post-war period except for a supply side shock occurring in 1974 arising from a coincidence of unrelated factors[28].

A simple initial text of this hypothesis was undertaken by fitting real prices against a constant. This highlighted the unusual nature of the 1974 peak which was dummied to produce the model detailed in equation (6.1).

$$\underset{}{ISSRPI_t} = \underset{(36.65)}{80.98} + \underset{(9.86)}{95.01}\ SHOCK \qquad (6.1)$$

$$R^2(adj) = 84.2\% \quad \text{regression } F = 97.28 \quad p = 0.000$$

where

ISSRPI = Imported sawn softwood real price index in year t: 1946-86 (1975 = 100)

SHOCK = 1 in 1974 (commodity price boom); 0 otherwise

Figures in brackets are t-statistics.

An additional time trend variable was added to equation (6.1) but this proved to be highly insignificant (t-value = 0.75). Therefore, although simple, this analysis gives strong support for the hypothesis of constant real prices during the post-war period.

An alternative approach is to use time series models (Pindyck and Rubinfeld, 1981). Various autoregressive, moving average and ARIMA models were estimated, with the strongest model being reported in equation (6.2).

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[26]In a similar recent supply and demand analysis, Whiteman (1995) also concludes that constant real softwood prices appears the most plausible forecast. In a further study, Whiteman (ibid) analyses planting and management costs to examine whether the ongoing trend away from exploitation and towards managed plantations will impact upon real prices. Again the best estimate is shown to be that real prices will remain constant into the foreseeable future.

[27]Prepared by Adrian Whiteman at the Forestry Commission, Edinburgh.

[28]Factors affecting major exporters included a particularly severe Scandinavian winter, political unrest in the USSR and industrial disputes in Canada (Colin Price, pers. comm.). These were compounded by increased transport costs as a result of the OPEC oil crisis.

$$\text{ISSRPI}_t = \underset{(22.61)}{56.49} + \underset{(1.44)}{0.309}\ \text{ISSRPI}_{t-1} + \underset{(2.72)}{0.523}\ e_{t-1} + e_t \qquad (6.2)$$

Mean = 81.75 (s.d. = 3.62)
df = 37
Residuals: SS = 3982.86 (back forecasts excluded)
MS = 107.64

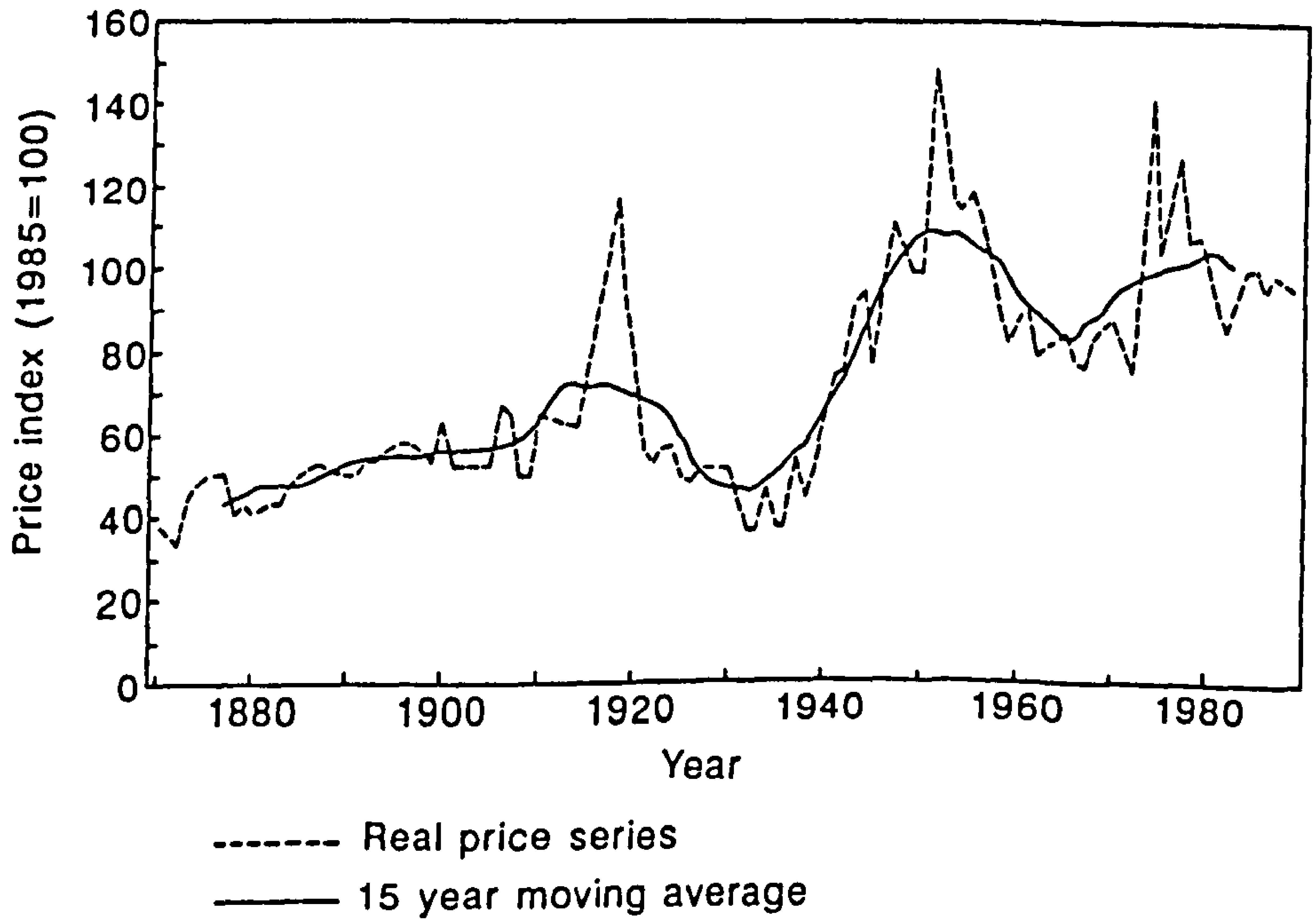
where:

e_t = estimation error in year t

The moving average element (e_{t-1}) of equation (6.2) shows that ISSRPI_t is related via a less than unitary coefficient of previous period prediction error. Furthermore the autoregressive element (ISSRPI_{t-1}) has a statistically insignificant impact upon present real prices. As before the strongest predictor is provided by the constant, supporting the hypothesis of constant real prices in the data period.

A number of other commentators have examined this issue, the majority concluding in favour of a constant real prices assumption (Doran, 1979; Price and Dale, 1982; Pearce and Markandya, unpublished). In a recent in depth analysis Whiteman (1995) undertakes a time series analysis of real softwood prices from 1870 to 1989. Figure 6.4 illustrates this series showing clear peaks due to WWI and WWII and the mid 1970's supply side shock referred to earlier.

Figure 6.4: The real price of sawn softwood imported into the UK[1] (1870-1989)



Note: 1. As discussed previously the UK domestic price is dictated by the world market
Source: Whiteman (1995)

Whiteman's best fitting time series model of this period indicates stable real prices (excluding shocks) prior to WWII, undergoing a shift to a higher level during the war and remaining at a higher, but again constant (excluding shocks), level after the war[29]. Whiteman's best estimate is therefore for a constant real softwood price for the foreseeable future[30].

6.3.1.3: Real prices for softwood - conclusions

Both our theoretical and empirical analyses give no support to the hypothesis of future increasing real prices for UK softwoods and an assumption of constant real prices is therefore adopted. However, one caveat should be highlighted regarding the use of time-series analyses to support such assumptions. These analyses are only strictly valid for forecasting if both overall demand and supply conditions remain reasonably stable. Future shocks might destabilise the existing market causing unforeseen real price changes.

6.3.2: HARDWOODS

While global reserves of coniferous forest have been reasonably stable or even grown over the past two decades, the post-war era has seen some decline in temperate hardwoods and a highly dramatic fall in tropical hardwoods. Considering first the case of UK hardwood reserves, the post-WWII period has seen a dramatic decline in the area of semi-natural hardwood woodlands. In England and Wales such woodland has more than halved from 142,000 ha in 1933 to 76,500 in 1983 (NCC, 1984). The bulk of this loss has been through conversion to mainly conifer plantations with the remaining losses generally attributable to agricultural encroachment (NCC, 1984; CPRE, 1992). However, in terms of overall area, broadleaved woodlands have actually increased since WWII as a result of new planting occurring particularly in the 1980's (see table 6.3).

While newly planted broadleaved woodland does not have the ecological value of ancient woodlands, it does represent an encouraging trend. However, as in the case of softwoods, the UK is far from self sufficient in hardwoods.

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[29] This finding concurs with our own supply and demand and time-series analyses which were restricted to the post-WWII period. Whiteman explains this wartime shift as arising from the loss of the British Empire (and inherent favourable terms of trade) which arose as a result of WWII.

[30] Whiteman notes that, even if the best fit time series model is disregarded in favour of a simple straight line through the entire dataset (see figure 6.4), this would only support a modest future real rise of about $^1/_2$% p.a.

Table 6.3: High forest by general species: Great Britain ('000 ha)

Forest type	1947	1965	1980	1994
Mainly coniferous high forest	397	922	1317	1516
Mainly broadleaved high forest	380	352	564	615
Total high forest	777	1274	1881	2131

Notes: Figures for 1947, 1965 and 1980 are from the occasional Census of Woodlands (FC, 1987; reproduced in Pearce, 1993). Figures for 1994 are from FC (1994a) and include some extrapolation from the 1980 Census.

Present levels of UK domestic hardwood (round and sawn) production are about 0.9 million m^3 annually, (FICGB, 1992). This compares with present demand of approximately 1.9 million m^3 per annum (ibid). While this represents a present self sufficiency rate of nearly 50% (i.e. much higher than for softwoods), this still means that the UK market is highly import dependent and consequently subject to fluctuations in the world market.

Global stocks of hardwoods have fallen dramatically in the post war period, primarily as a result of deforestation in the developing, tropical countries of the world in which they are predominant. The principle cause of this deforestation is as a direct result of population pressures which, exacerbated by widespread and growing LDC poverty, has led to an increased demand for fuelwood for basic energy needs (World Resources Institute, 1994)[31]. Two further pressures upon supplies have been developed world demand for tropical hardwoods[32] (Whiteman, 1995) and forest burning for agricultural expansion[33] (Myers, 1990). Table 6.4 details deforestation in 26 major hardwood producing tropical countries (which includes estimates of the carbon release engendered by this deforestation - see discussions in chapter 8).

[31]World production of non-coniferous roundwood currently stands at roughly 2 billion m^3 per annum (1991 figures; forecast to rise to 3 billion by 2011). Of this about $^3/_4$ is consumed in developing countries, mainly as fuelwood (figures from Whiteman, 1995).

[32]Major export markets are (in order of magnitude) the USA, Japan, China and Europe (Collins, 1991).

[33]This latter factor provides a significant source of greenhouse gas emissions. These are quantified on an annual basis in table 6.4.

Table 6.4: Tropical deforestation to 1989 (inclusive)

Country (plus area)	Original forest cover (km^2)	Present forest cover (km^2)	Present primary forest (km^2)	Current deforestation 1989	Carbon Release in 1989	
				km^2 p.a. (%)	million tonnes	(% of total)[4]
Bolivia (1,098,581)	90,000	70,000	45,000	1,500 (2.1)	14	1.0
Brazil (8,511,906)	2,860,000	2,200,000	1,800,000	50,000 (2.3)	454	32.1
Cameroon (475,442)	220,000	164,000	60,000	2,000 (1.2)	28	2.0
Central America (522,915)	500,000	90,000	55,000	3,300 (3.7)	30	2.1
Colombia (1,138,891)	700,000	278,500	180,000	6,500 (2.3)	59	4.2
Congo (342,000)	100,000	90,000	80,000	700 (0.8)	10	0.7
Ecuador (270,670)	132,000	76,000	44,000	3,000 (4.0)	27	1.9
Gabon (267,670)	240,000	200,000	100,000	600 (0.3)	9	0.6
Guyanas[5] (469,790)	500,000	410,000	370,000	500 (0.1)	4	0.3
India (3,287,000)	1,600,000	165,000	70,000	4,000 (2.4)	41	2.9
Indonesia (1,919,300)	1,220,000	860,000	530,000	12,000 (1.4)	124	8.9
Ivory Coast (322,463)	160,000	16,000	4,000	2,500 (15.6)	36	2.6
Kampuchea (181,035)	120,000	67,000	20,000	500 (0.8)	5	0.4
Laos (236,800)	110,000	68,000	25,000	1,000 (1.5)	10	0.7
Madagascar (590,992)	62,000	24,000	10,000	2,000 (8.3)	28	2.0
Malaysia (329,079)	305,000	157,000	84,000	4,800 (3.1)	50	3.6
Mexico (1,967,180)	400,000	166,000	110,000	7,000 (4.2)	64	4.6
Myanma[6] (696,500)	500,000	245,000	80,000	8,000 (3.3)	83	5.9
Nigeria (924,000)	72,000	28,000	10,000	4,000 (14.3)	57	4.1
Papua[7] (461,700)	425,000	360,000	180,000	3,500 (1.0)	36	2.6
Peru (1,285,220)	700,000	515,000	420,000	3,500 (0.7)	32	2.3
Philippines (299,400)	250,000	50,000	8,000	2,700 (5.4)	28	2.0
Thailand (513,517)	435,000	74,000	22,000	6,000 (8.4)	62	4.4
Venezuela (912,050)	420,000	350,000	300,000	1,500 (0.4)	14	1.0
Vietnam (334,331)	260,000	60,000	14,000	3,500 (5.8)	36	2.6
Zaire (2,344,886)	1,245,000	1,000,000	700,000	4,000 (0.4)	57	4.1
Totals	13,626,000[1]	7,783,500[2]	5,321,000[3]	138,600 (1.8)	1,398	100.0

Notes:
1. Equals 97 per cent of estimated total original extent of tropical forests, around 14 million km^2
2. Equals 97.5 per cent of present total extent of tropical forests, 8 million km^2
3. Equals 67 per cent of total remaining tropical forests, 8 million km^2
4. Omits countries not on this list as minor
5. French Guiana, Guyana and Surinam
6. Burma
7. Papua New Guinea.

Source: Myers (1990)

Annual net hardwood extraction rates have risen from 0.8% at the end of the 1970's (Doran, 1979) to 1.8% a decade later (Myers, 1990); rates that mean that by 2010 only Brazil and Zaire will have any significant remaining areas of rainforest (Collins, 1991). Given that these represent the richest global environment for biodiversity, this has already led to rates of species extinction unprecedented in the history of the world (MacNeill, 1990; World Resources Institute, 1994; Pearce and Warford, 1993).

Setting aside the terrible ecological consequences of this destruction, the non-sustainability of such loss means that current hardwood supply levels cannot be maintained. Compared with a growth in UK demand of up to 3.5% per annum (Hart, 1987) the potential exists for increases in real price levels. In a review of such arguments, Bateman (1987) reports 'pro-forestry' estimates ranging from 0.5% to 4% annually[34]. However, this is balanced by opposing views such as that of Whiteman (1995), that while demand will increase, "it should be possible to improve forest management to meet these demands, which would then keep timber prices relatively stable". Certainly the rate of growth of hardwood planting detailed in table 6.3 means that the current rate of UK self sufficiency will rise considerably providing some element of a domestic buffer from any future reduction in global supplies[35].

This is clearly an area of uncertainty and disagreement. While we feel that there is a considerably stronger case for real price increases for hardwoods than softwoods, we have here adopted a zero real price rise assumption on the grounds that any alternative rate has major consequences for the long delayed timber benefits of hardwood plantations and that using a zero rate allows us to more easily revise our calculations in the light of subsequent improved information.

6.4: GRANTS

6.4.1: HISTORICAL BACKGROUND

Given the long delayed nature of forestry returns, government incentives have always played a major role in UK private-sector planting decisions. The earliest incentives coincided with the establishment of the FC when, in 1919, a scrub clearance and ground preparation grant was introduced. A second planting grant scheme, introduced in 1927, established an enduring trend for broadleaves to be given preferential subsidy rates over conifers[36], reflecting an early recognition of non-strategic/production objectives within forestry policy.

Following WWII a variety of FC administered schemes were introduced. Through

[34]Estimates are from Johnston et al (1967); Doran (1979); Burnham (1985) and Hart (1987).

[35]Although such pressures would still act upon prices if global demand became significantly supply constrained.

[36]This planting grant paid £2/acre for conifers and £4/acre for hardwoods (Johnson and Nicholls, 1990).

examination of these we can see a gradual movement in forestry policy objectives from simply maximising timber production (e.g. the Dedication Scheme: Basis I) to schemes giving equal emphasis to timber, environmental and recreational goals (e.g. Dedication Scheme: Basis III; Broadleaved Woodland Grant Scheme). Table 6.5 charts the development of these schemes.

Table 6.5: Forestry Commission administered grant schemes 1948-85

Grant	Inaugurated	Closed	Structure
Dedication Basis I Dedication Basis II Dedication Basis III	1948 1948 1974	1972 1972 1981	Annual grant Planting grant (from 1977 also a management grant)
Small Woods Planting Grant Approved Woodlands Scheme Small Woods Grant	1950 1953 1977	1971 1972 1981	For smaller areas Planting grant Woodland areas between 0.25 ha and 10 ha
Forestry Grant Scheme Broadleaved Woodland Grant Scheme	1981 1985	1982 1988	Planting grant only Planting grant only

Source: Johnson and Nicholls (1991)

While grants were important, as discussed at the start of this chapter the overriding force behind the expansion of private sector forestry in this period was tax concessions. The scrapping of most of these concessions in the 1988 Budget[37] has thrust the role of grants centre-stage and it is these which are likely to be the main motivators of any expansion in the foreseeable future.

6.4.2: PRESENT SITUATION

6.4.2.1: Forestry Commission administered grants

Throughout the 1980's the FC emphasised its reorientation away from the simple pursuit of timber output and towards wider objectives (FC, 1985c). Such policy was

[37]See Lynch (1989) for a review of the present tax situation.

embodied in the introduction, in 1988, of the Woodland Grant Scheme (FC, 1988b). This was designed to encourage the multi-purpose use of woodland with the following objectives:

i. to encourage timber production;
ii. to provide employment in areas of rural depopulation;
iii. to enhance landscape, create wildlife habitat and provide longer term recreation and sporting facilities;
iv. to encourage the conservation and regeneration of existing woodlands.

Rates of support under the WGS were revised in 1990 as detailed in table 6.6.

Table 6.6: Woodland Grant Scheme (£/ha)

Area planted	Conifers	Broadleaves
0.25-0.9 ha	1005	1575
1.0-2.9 ha	880	1375
3.0-9.9 ha	795	1175
10 ha+	615	975

Source: Johnson and Nicholls (1991)

Payments under the WGS are made in three instalments: 70% at planting, 20% after 5 years and 10% after a further 5 years (subject to satisfactory establishment). In addition to this a Better Land Supplement (BLS) is payable for planting on arable/improved grassland cultivated (including ploughing) within the previous 10 years. BLS is £400/ha for conifers or £600/ha for broadleaves, all payable at planting.

Further enhancement of this package was provided in 1992 by the introduction of the Woodland Management Grant (WMG). This provides an annual addition to the WGS, payable after the first 10 years of establishment in return for the setting down and execution of 5-yearly management plans designed to increase the environmental value of the woodlands concerned. Table 6.7 details WMG payments.

Table 6.7: Woodland Management Grants (£/ha per annum)

Type of WMG	Period of eligibility (age of wood in years)	Rate of grant (£/ha/pa)
Standard WMG[1]		
Conifer	11-20	10
Broadleaved	11-40	25
Special WMG[1,2]	11 onwards	35
Supplement for small woods[3]		
Standard: conifer	11-20	5
Standard: broadleaf	11-40	10
Special[4]	11 onwards	10

Notes:
1. All these grants are also payable as *additions* where the owner is a farmer under the Farm Woodland Scheme, as compensation for agricultural output foregone (not against establishment costs).
2. Higher rates are available for woodlands of special environmental value (nature conservation, landscape or public recreation). The owner will be expected to maintain the wood's character. These grants are available for any forest of any age over 10 years, however, they may be extended to younger or even proposed forest if the Forestry Commission is satisfied that there is demand for such a provision.
3. Available as additions for all woodlands of less than 10 ha (of correct age).
4. Available for any woodland (over 10 years) of less than 10 ha where the woodland is of special environmental value.

Source: Johnson and Nicholls (1991)

1991 also saw the FC introduce the Community Woodland Supplement (CWS), a further addition to the WGS (and WMG) designed to promote recreational woodlands "within 5 miles of the edge of a town or city and in an area where the opportunities for woodland recreation are limited" (FC, 1991). In implementation (FC, pers. comm., 1993) this has been translated very broadly so that relatively small communities of just a few thousand people are considered sufficient to justify payment of CWS. The scheme consists of a single payment of £950/ha payable at planting. All woodlands qualifying for CWS were allowed WGS and WMG, the latter being paid at the enhanced 'special' rate.

In addition to the above, from 1992 the FC offered a single £100 flat rate payment for each new woodland (irrespective of size) provisional on the drawing up of a management plan (FC, 1991)[38].

[38] In addition to this the FC also provides certain other grant payments for general and coppice management, open spaces and grey squirrel control. Details are given in Johnson and Nicholls (1991).

6.4.2.2: Ministry of Agriculture, Fisheries and Food (MAFF) grant schemes

In 1988 MAFF introduced the Farm Woodland Scheme (FWS) to provide annual income support[39] to farmers who establish woodlands on what was previously agricultural land (MAFF, 1987)[40]. The scheme has almost identical objectives to the FC's WGS (and is payable concurrently) with the additional goal of reducing surplus agricultural production. As a consequence higher rates of FWS are payable on better quality land. Although these rates do not distinguish between conifer and broadleaf woodlands, the period of annual support is longer for the latter.

Initial expectations regarding the impact of the joint FWS/WGS package were mixed. While Kula (1989) felt that the new scheme would "no doubt encourage a lot of new investors into the industry", our own analysis (Bateman, 1988b) suggested that the initial rates of grant would only attract very marginal areas out of agriculture[41]. In the event we feel that our predictions were borne out. Fearn (1990) reports that, with the exception of a few farmers entering the scheme for non-economic reasons[42], the scheme attracted very few applicants during its initial period.

Consequently, in 1992, the FWS was replaced by the Farm Woodland Premium Scheme (FWPS) (MAFF, 1992a,b,c). Here farms first applied to the FC for planting grants under the WGS (including BLS, WMG, CWS and the single new woodland payments where appropriate). If approved the farm could then apply to MAFF for FWPS payments as detailed in table 6.8.

For woodlands consisting of less than 50% broadleaves the FWPS is payable in each of the first 10 years after planting, a period which is extended to 15 years for mainly broadleaved woodlands[43]. However, grant repayments with interest are stipulated if land is returned to agriculture within 20 years for the former and 30 years for the latter (MAFF, 1992b). At the time of writing it is still too early to fully assess the impact of the FWPS.

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[39]The FWS also pays planting grants but, since its revision in 1992 these are identical to those offered under the WGS. Farmers may not collect both FWS and WGS planting grants.

[40]Initial rates of FWS and contemporary WGS levels are detailed in Bateman (1988b).

[41]For example, the initial WGS was calculated to only outperform sheep-stocking densities of less than one ewe/ha (Bateman, 1998b).

[42]The prime reason for entry to the initial WGS was for ornamental planting around farm-gardens (Fearn, 1990). Therefore, the scheme ironically favoured rich farmers who would probably have undertaken such planting anyway.

[43]This is considerably more front-loaded than the original FWS which provided lower annual sums but over a longer period (see Bateman, 1988b).

Table 6.8: Annual payments under the Farm Woodland Premium Scheme[1] (£/ha per annum)

Present use	Lowlands	Less favoured areas	
		DA	SDA
Arable/improved grassland	250	190	130
Unimproved	n/a	60	60

Notes: n/a = not available
1. The following FWPS restrictions apply: (i) not more than 50% of farm eligible; (ii) not more than 40 ha of unimproved land per farm; (iii) eligibility for arable/improved grassland restricted to land under such usage within the previous three years; (iv) the FWPS as a whole is cash rather than area limited. Further details are given in MAFF (1992b).

Source: MAFF (1992b)

Farms may also convert land into forestry under the Common Agricultural Policy (CAP) Set-Aside scheme. Set aside woodland is not eligible for either FWPS annual payments or WGS BLS. However, standard WGS payments may be received concurrently with set-aside in high productivity areas. For the purposes of this study, the set-aside guidelines reported in Johnson and Nicholls (1991) indicate that very little of the area under consideration (Wales) would qualify for concurrent WGS and set-aside payments and we consequently do not pursue this particular permutation any further.

6.4.2.3: Other schemes and regulations

With respect to our Welsh study area, the creation of the Cambrian Mountains and Lleyn Peninsula Environmentally Sensitive Areas (ESA's) in 1986 and 1987 (respectively) seems to offer the possibility of further grants for broadleaved woodland. Welsh Office (1989a) stresses the importance of such features within the Cambrian Mountains ESA while in a subsequent leaflet (Welsh Office, 1989b) payments of £45/ha per annum are specified for management of such woodlands. These are clearly specified as additions to existing planting and management grants. However, subsequent publications regarding the Lleyn Peninsula ESA offer lower rates of grant (£15/ha per annum) restricted to existing broadleaf woodland alone (Welsh Office, 1992a,b). Conversations with both ESA authorities indicate that these anomalies still persist today.

Further grants towards the costs of promoting landscape or countryside conservation are occasionally paid by the Countryside Commission and Nature Conservancy Council (Johnson and Nicholls, 1991) while ADAS can provide certain technical support. However, the occasional nature of such projects means that they are not considered further in this study.

A factor which may become of increasing importance is the developing planning framework around woodland. During conversations with the FC[44], the author was informed that farmers would only be granted felling licences subject to a replanting order. While future policy may change, in effect this means that once farmers place land under trees they may well become legally bound to maintain an equal area of woodland on the farm in perpetuity. This irreversibility, if it became widely known, would we believe, be a major brake upon farm-woodland expansion. However, as such licences will not be sought for the best part of two decades, there may be a significant information lag in this system.

Another important development is the increasing involvement of the Department of the Environment (DoE), the ultimate national planning authority, in forestry expansion. Concerns regarding the aesthetic and environmental impact of monoculture conifer plantations led to an announcement in March 1988 that planning permission for such plantations would not normally be granted for sites in England. The possibility of extension to Wales and Scotland still exists although the subsequent changes in tax-law have lessened the pressure for such developments. This slowing of conifer expansion was also given a European dimension in the same year with the implementation of the Environmental Assessment (Afforestation) Regulations. These rules, derived from EC Directive 85/337, state that any applicant for FC assistance may be required to submit an environmental assessment of the proposed forest. In practice such assessments have become routine requirements for plantations of over 100 ha affecting National Nature Reserves, National Parks, Sites of Special Scientific Interest, etc. The EC has also provided for the further funding of the Countryside Commission schemes mentioned above.

6.4.3: Grants: conclusions

Farmers considering diverting land into forestry are eligible for a variety of grants and

[44]In particular with the Chief Forester, Santon Downham, Thetford Forest, April 1993.

subsidies. These vary considerably according to which scheme they register under and, to a lesser degree, upon locational factors. In the following section we incorporate these subsidies within the wider costs and revenues arising from plantation management.

6.5: PLANTATION COSTS AND REVENUES

6.5.1: CHOICE OF SPECIES

Ideally one would wish to analyse all those species which are likely to be used in a conversion from agriculture to forestry. The feasibility of such an analysis was investigated by use of the FC's Forestry Investment Appraisal Programme (FIAP). However, while this is an excellent tool for the management of given stands, it was not amenable to the type of modification required to answer the questions posed by this research. Consequently it was decided that two representative species, one conifer the other broadleaf, would be chosen for study.

Amongst the eight major species of conifer grown commercially in the UK[45], the Sitka spruce stands out as by far the most dominant constituting 28% of total forest area, more than double any other species (FICGB, 1992). The species is capable of producing an average annual yield of 24m^3/ha over an optimal rotation with typical UK productivity averaging 12-16m^3/ha. This dramatic growth rate means that optimal felling ages can be very short, from 60 years on poor ground to as little as 45 years on good sites[46]. Choice of Sitka spruce as a representative conifer species therefore reflects a logical and often observed timber-productivity choice. However, this species is not thought to be optimal in terms of recreation value.

Interestingly there is little empirical evidence regarding a connection between species and recreation value. In one of the few valuation studies to consider this, Hanley and Ruffell (1992)[47] fail to isolate a significant relationship here. This may mean that all woodland recreation valuation studies are observing values for outdoor, rather than specifically

[45]In descending order of total forest area, major conifers are: Sitka spruce (28%); Scots pine (13%); lodgepole pine (7%); Japanese larch (6%); Norway spruce (6%); Corsican pine (2%); Douglas fir (2%); European larch (2%). Major hardwood are: oak (9%); ash (4%); beech (4%); birches (4%). The remaining area consists of a diversity of species (FICGB, 1992).

[46]As discussed subsequently optimal felling age is a function in part of discount rate rather than just of growing conditions.

[47]See review in appendix 1.

woodland, activities. However, if we temporarily lurch from the empirical to the anecdotal, it is the authors firm belief that walkers *do* recognise and appreciate the difference between the claustrophobic atmosphere produced by a species like Sitka spruce (with its dense entanglement of lower branches, tightly packed together to maximise timber yield, set in a bed of stultifying acid pineneedles) and, say, the much more airy and open feel of a Scots pine woodland. An even clearer difference is evident when we then consider the gorgeous spaciousness, beautiful trunks and foliage, and verdant undergrowth of an oak woodland.

To allow for this difference we determined to extend our appraisal to consider a representative hardwood. Here the choice is more difficult as the oak is the most abundant broadleaf species but is relatively slow growing and less productive than the beech which we decided to study as a more viable hardwood alternative.

6.5.2: SITKA SPRUCE COSTS AND REVENUES

6.5.2.1: Costs

Irrespective of species, the majority of plantation costs occur at the start of the rotation (planting, etc) and at felling. Here we make the common FC assumption that all cutting costs (both thinnings - the extraction of undersized trees at set points during the rotation so as to maximise long run plantation yield - and felling) are either carried out by contractors or incur contractor-level implicit costs upon the plantation operator. This allows us to use the standing timber price-size curve (see subsequent sections) and effectively ignore these costs[48]. Remaining costs are detailed in table 6.9.

The costs detailed in table 6.9 will vary in individual cases according to spatial factors such as infrastructure, distance to sawmills, local variation in input supply prices (including labour), etc. Typical values for such parameters are incorporated within the base data of table 6.9 (FC, 1987). They will also vary according to the intensity of planting. Here, typical parameters are chosen with trees being planted 2m apart.

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[48]As a side analysis we produced the following model of felling costs from data given in Hart (1991).

COST = 8.98 - 0.145 YC

where:

COST	=	clearfelling cost (£/m^3 at 1990/91 prices)		
YC	=	yield class (see subsequent definition)		
R^2(adj)	=	69.3%	F = 21.33	p = 0.000

Table 6.9: Conifer plantation costs (£/ha, 1990 prices)

Years from planting[1]	Cost (£/ha)	Cost items
0	647.45	Construct maintenance roads[2], plough land, other land preparation, initial drainage, new fencing, purchasing plants, planting, initial fertilizer.
1	174.86	Beating up[3], weeding, maintenance
2	101.08	Weeding, maintenance
3	68.19	Weeding, maintenance
4-6	22.06	Maintenance
7	114.94	Cleaning, maintenance
8	54.42	Subsequent fertilizer, maintenance
9	22.06	Maintenance
10	60.17	Respacing, maintenance
11-19	22.06	Maintenance
20	109.20	Pruning, maintenance
21-(F-1)	22.06	Maintenance

In addition a cost of £285.03 is incurred in the year preceding the first thinning (varies according to growth rate) for construction of forwarder roads and transporter points.

Notes: 1. Planting year = year 0; felling year = year F (F varies across growth rate and discount rate, see subsequent discussions).
2. Costs such as road construction, ploughing, etc are based on average probabilities that such tasks will be necessary. Base data also considers incidence of unplantable areas (rocky outcrops, etc).
3. For explanation of this and other terms see Hart (1987, 1991).

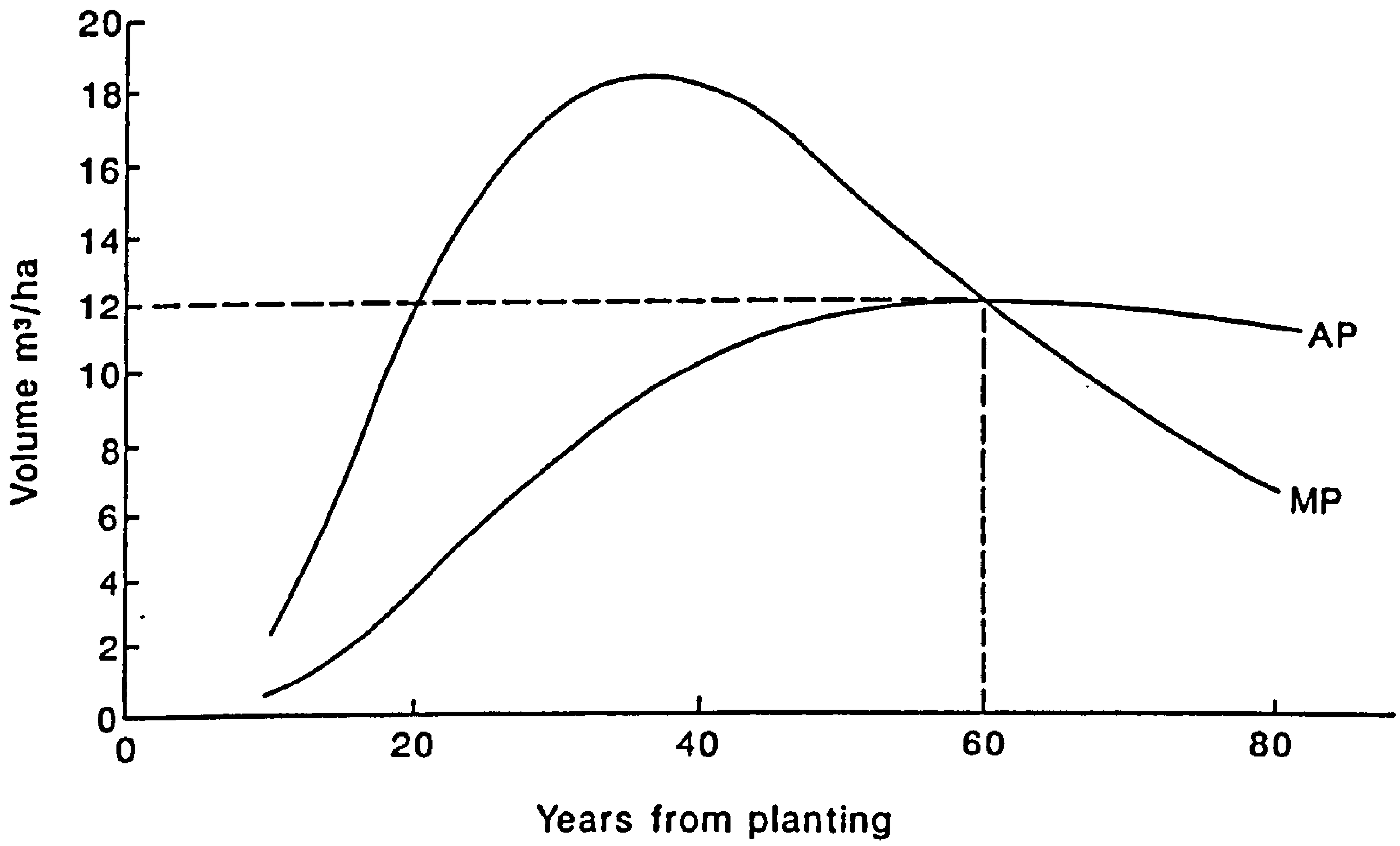
Sources: FC (1987); Bateman (1987); Hart (1987, 1991).

6.5.2.2: Timber revenues

As with most enterprises the general objective of the forest manager can be assumed to be profit maximisation. With regard to timber output, two factors are of particular importance here: (i) the rate of growth; (ii) the rate of discount. However, in order to understand the impact of these factors it is useful to first hold both constant and consider a single plantation.

Trees are ideal material for economic analysis as they are, in microeconomic terms, 'well-behaved' production systems exhibiting initially increasing and subsequently diminishing marginal product (MP) curves. Figure 6.5 shows a typical timber MP and corresponding average product (AP) curve. The intersection point defines the maximum average annual increment in volume which a stand can deliver (in this case 12m^3/ha per annum), otherwise known as its yield class (YC).

Figure 6.5: Marginal and average product curves for an even age stand of YC12 trees

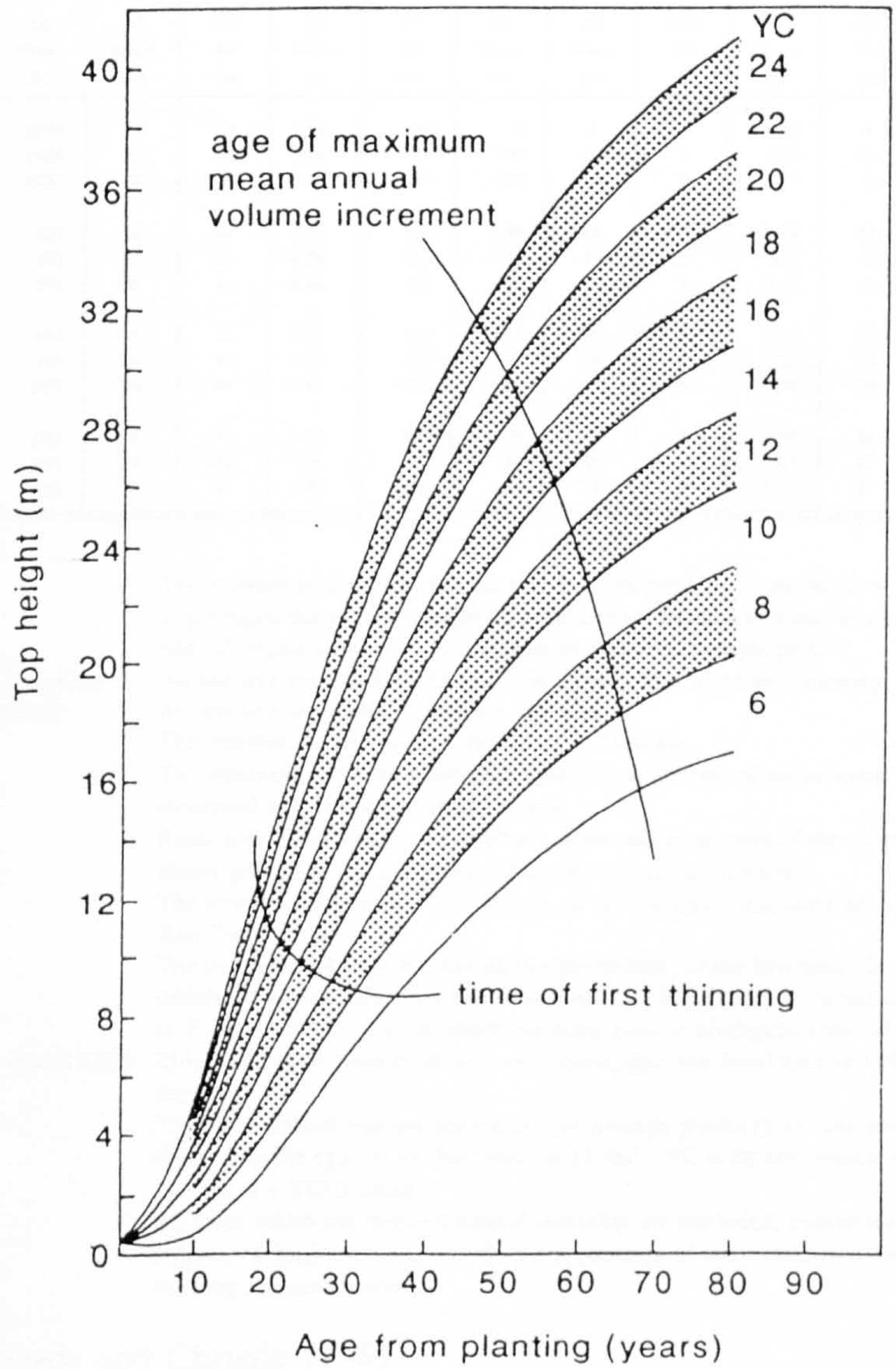


Notes: MP = marginal product (otherwise known as the mean annual volume increment: MAI)
AP = average product (otherwise known as the current annual increment: CAI).

Source: adapted from Edwards and Christie (1981)

YC therefore measures the production capacity of a particular stand. For planning purposes YC can be measured by relating plantation age to the observed average top height of the trees in that stand. Figure 6.6 illustrates YC curves for Sitka spruce superimposed by a line showing the age at which annual average product is maximised. This latter curve shows that the faster a tree grows, the sooner it will maximise average product.

Figure 6.6: General yield class curves for Sitka spruce



Source: Edwards and Christie (1981)

Since its inception in 1919 the Forestry Commission has collected data quantifying the characteristics of plantations growing at differing YC. These 'yield models' have now been collated across varying species and management regimes (Edwards and Christie, 1981). Table 6.10 illustrates the yield model for YC12 Sitka spruce planted at 2.0m spacing and thinned under the Forestry Commission's standard guidelines.

Table 6.10: Yield model for YC12 Sitka spruce (2.0m spacing; intermediate thinning)

	MAINCROP after Thinning						Yield from THINNINGS					CUMULATIVE PRODUCTION		MAI	
(1) *Age* *yrs*	(2) *Top* *Ht*	(3) *Trees* */ha*	*(4)* *Mean* *dbh*	*(5)* *BA* */ha*	*(6)* *Mean* *vol*	(7) *Vol* */ha*	*(8)* *Trees* */ha*	*(9)* *Mean* *dbh*	*(10)* *BA* */ha*	*(11)* *Mean* *vol*	*(12)* *Vol* */ha*	*(13)* *BA* */ha*	*(14)* *Vol* */ha*	*(15)* *Vol* */ha*	*(16)* *Age* *yrs*
20	7.3	2309	11	24	0.03	66	0	0	0	0.00	0	24	66	3.3	20
25	10.0	1450	15	25	0.06	91	799	12	9	0.05	42	34	133	5.3	25
30	12.5	1057	18	28	0.12	131	393	15	7	0.11	42	44	215	7.2	30
35	14.9	827	22	32	0.22	180	230	18	6	0.18	42	53	306	8.7	35
40	17.2	678	25	34	0.34	231	150	21	5	0.28	42	61	399	10.0	40
45	19.2	571	29	36	0.49	278	107	23	5	0.39	42	68	488	10.8	45
50	21.0	492	31	38	0.65	319	79	26	4	0.51	40	73	570	11.4	50
55	22.5	439	34	39	0.81	357	53	28	3	0.64	34	78	642	11.7	55
60	23.7	401	36	40	0.97	390	37	30	3	0.78	29	82	704	11.7	60
65	24.8	373	37	41	1.12	418	28	32	2	0.93	26	85	758	11.7	65
70	25.7	351	39	42	1.26	443	22	33	2	1.05	23	88	805	11.5	70
75	26.5	332	40	43	1.40	465	19	35	2	1.10	21	90	848	11.3	75

Glossary of terms:

Age: The number of growing seasons that have elapsed since the stand was planted.

Top Ht: Top height; the average height of a number of 'top height trees' in a stand, where a 'top height tree' is the tree of largest breast height diameter in a 0.01 ha sample plot.

MAINCROP after Thinning: All the live trees left in the stand, at a given age, after any thinnings have been removed.

Yield from THINNINGS: All the live trees removed in the thinning.

Trees/ha: The number of live trees in the stand, per hectare.

Mean dbh: The quadratic mean diameter (the diameter of the tree of mean basal area) in centimetres, of all live trees measured at 1.3m above ground-level.

BA/ha: Basal area. The sum of the overbark cross-sectional areas of the stems of all live trees, measured at 1.3m above ground-level, and given in square metres per hectare.

Mean vol: The average volume, in cubic metres, of all live trees, including any with a breast height diameter of less than 7cm.

Vol/ha: The overbark volume, in cubic metres per hectare, of the live trees. In conifers, all timber on the main stem which has an overbark diameter of at least 7cm is included. In broadleaves, the measurement limit is either to 7 cm, or to the point at which no main stem is distinguishable, whichever comes first.

CUMULATIVE PRODUCTION: This is the main crop basal area or volume, plus the basal area or volume of the present and all previous thinnings.

MAI (and YC): The mean annual volume increment (or average product); i.e. the cumulative volume production to date divided by the age. Here this peaks at $11.7m^3$. YC is by convention rounded to the nearest even number, i.e. this is a YC12 stand.

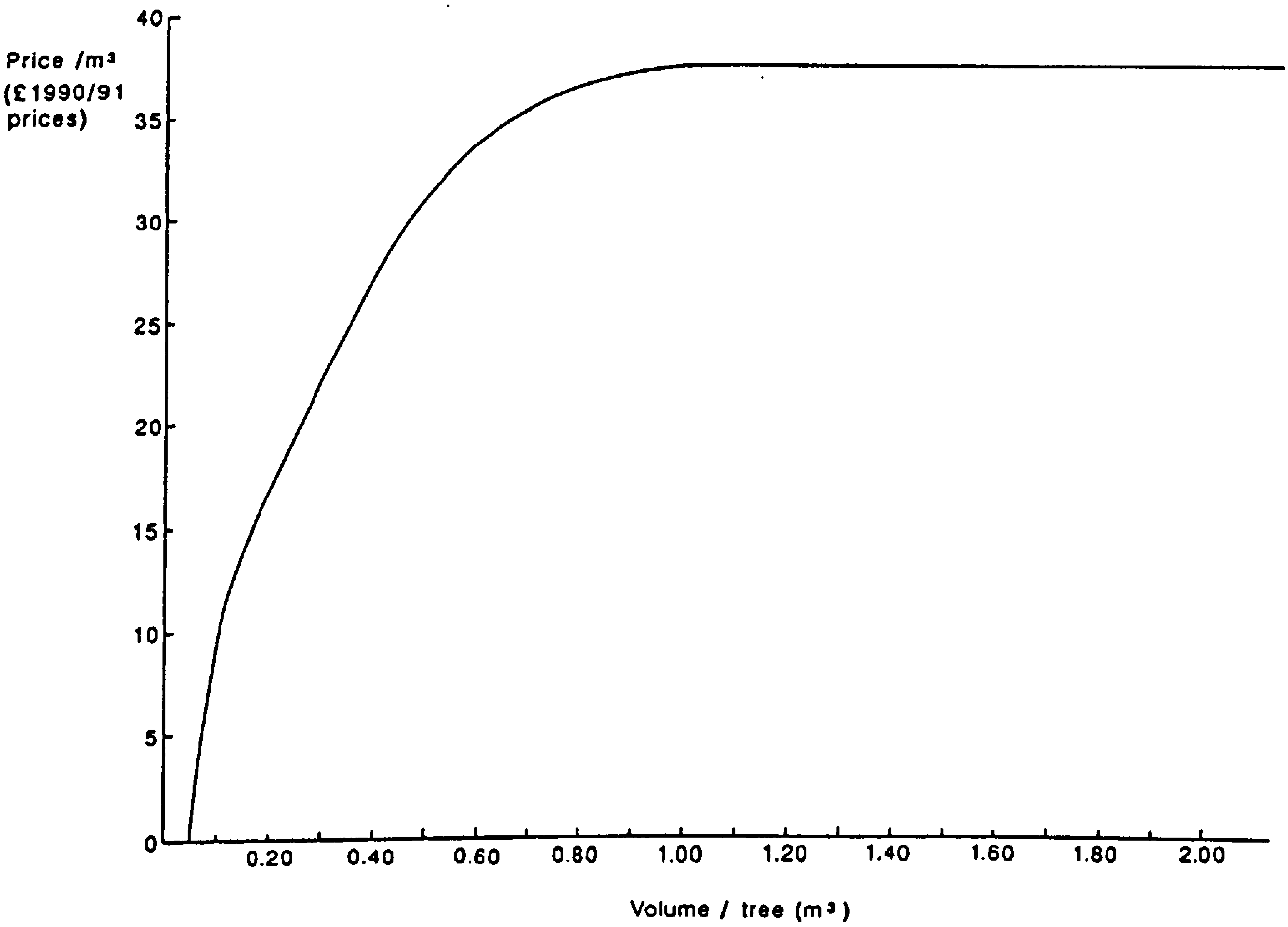
Note: All trees which die through natural mortality are excluded, except that in models of unthinned stands the volume of dead trees, expressed as a percentage of the cumulative volume production, is given under the heading *per cent mortality*.

Source: Edwards and Christie (1981).

The yield curve for each YC is given in the first two columns of the yield model (table 6.10) while the third column lists the number of trees left in the stand (the 'maincrop') after each thinning, details of which are given in columns (8) to (12). The value of the maincrop at felling is given by multiplying the volume/ha, shown in column (7), by the price/m^3. However, price is itself a function of the mean volume per tree (given in column (6)) which is in turn a function of felling date. Simply put, when trees are thin they are of limited use and so their price/m^3 is low. As trees increase in volume so their usefulness and therefore price/m³, rises. This continues (at a diminishing rate) to the point where their girth (see column (5) of table 6.10) is such that the tree can be used for sawn wood, telegraph poles and myriad other products. After this point the price/m³ remains fairly constant and the value of a stand increases only as much as volume does.

Estimation of this 'price-size' curve has been the subject of repeated statistical investigation by the FC (Mitlin, 1987; Whiteman, 1990; Sinclair and Whiteman, 1992). In this study we adopted the findings of Whiteman (1990), primarily because this uses the same base year as our wider study, but also because this analysis recognises that prices are higher in England and Wales than in Scotland and therefore provides a significantly better fit to the data (R^2 = 87.5%) than Sinclair and Whiteman's subsequent unified analysis (R^2 = 74.7%). Figure 6.7 illustrates the price-size curve used in our analysis.

Figure 6.7: Price size curve for conifers in England and Wales (£; 1990/91 prices)



Source: drawn from data given in Whiteman (1990)

The value of thinnings is calculated in a similar manner except that, whereas maincrop revenues are only collected once (at felling), once commenced thinning takes place on a regular (usually five yearly) basis. The FC yield models give information on when thinning should commence (approximately year 20 although this varies across YC).

The felling date therefore emerges as a key factor in determining the overall value of a stand. As mentioned this will vary according to both the YC concerned and the discount rate employed. As figure 6.6 showed, the faster a tree grows the sooner it reaches its age of maximum annual average product. Therefore as YC increases, optimal felling age falls. This is exacerbated by discounting, i.e. the higher the discount rate the lower the optimal felling age.

The impact of varying YC and discount rate upon optimal felling age was calculated using the FIAP software mentioned above. FIAP operates by maximising the net present value of a stand subject to several user-determined parameters. Results from this analysis are given in table 6.11.

With felling year established we can now calculate both maincrop and thinnings revenues for each stand. However, it was felt that FIAP was insufficiently flexible to conduct our further analysis and therefore yield models for YC6-24 Sitka spruce were encoded into a database for use within the MINITAB statistical package (MINITAB, 1994). A particular advantage of this approach was that the software allows the researcher to design custom written macro's, facilitating complex and/or repetitive data analysis.

6.5.2.3: Combining timber revenues with subsidies and cost streams

As discussed previously in this chapter, grants and subsidies constitute a major source of revenue for the woodland operator which may, due to their relatively early receipt, outstrip the discounted value of felling revenues. The array of available grants discussed previously can be simplified to 12 possible subsidy payment stream permutations. Table 6.12 details these along with timber benefit revenues and plantation costs for one YC/discount rate combination (YC24, discounted at a real rate of 6%, giving an optimal felling age of 41 years)[49].

[49]This combination is chosen for illustrative purposes (to ensure a reasonably short rotation). Note that as planting occurs in year 0, felling occurs in year 40 (as per table 6.11).

Table 6.11: Optimum felling age for various discount rates: Sitka spruce, YC6-24

Yield Class (Sitka spruce)	Discount rate (%) 2	3	4	5	6	8	10	12
6	80	73	68	64	60	54	50	47
8	78	72	67	62	58	53	48	44
10	74	69	64	60	56	51	47	43
12	70	63	58	56	54	50	46	42
14	69	60	54	52	50	47	44	41
16	68	58	51	49	47	44	42	40
18	66	57	50	46	43	42	40	38
20	66	57	50	44	42	40	38	36
22	66	56	49	44	41	37	36	34
24	65	56	48	44	40	35	34	33

Notes: Optimal felling age maximises NPV given the relevant discount rate (r) and YC combination. The above figures treat the planting year as year 0. The table was calculated using FIAP running at the Forestry Commission Headquarters at Edinburgh (except for the row for r = 3% which was interpolated). The author is obliged to Jane Sinclair and Roger Oakes at Edinburgh for assistance.

The table is calculated according to the following assumptions:

Spacing: 2.00 x 2.00
Thinning: Line, MTT
Delay on first thinning: None
Stocking: 85%
Successor crop NPV: Zero
Price size curve: G.B. conifer 1992
Thinning price differential (£ 1992/93): £0.30 /m^3
Charge per m^3 (£ 1992/93) : £3.68 /m^3

6.5.3: BEECH COST AND REVENUES

6.5.3.1: Costs

Information on hardwood planting costs is far less readily available than for conifers. Data was collected both from interviews with managers of broadleaf woodlands[50] and from

[50]Notably Fred Lewis, Kerswell, Exminster and Cyril Hart, Chenies, Dean.

Table 6.12: Revenue (including subsidies) and cost streams for an optimal rotation of YC24 Sitka spruce with a 6% discount rate: 1990 prices

Age	Maincrop					Thinnings					Costs
t	M.trees	M.AvVol	M.Vol/ha	M.price	M.ben	T.trees	T.AvVol	T.Vol/h	T.price	T.ben	Costs
0	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	647.45
1	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	174.73
2	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	101.08
3	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	68.19
4	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
5	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
6	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
7	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	114.94
8	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	54.42
9	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
10	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	60.17
11	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
12	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
13	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
14	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
15	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
16	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
17	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	307.09
18	0	0	0	0.00	0.00	1172	0.07	84	4.98	418.32	22.06
19	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
20	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	109.20
21	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
22	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
23	0	0	0	0.00	0.00	348	0.24	84	23.12	1942.08	22.06
24	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
25	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
26	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
27	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
28	0	0	0	0.00	0.00	166	0.51	84	31.60	2654.40	22.06
29	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
30	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
31	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
32	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
33	0	0	0	0.00	0.00	99	0.85	84	37.11	3117.24	22.06
34	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
35	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
36	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
37	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
38	0	0	0	0.00	0.00	66	1.28	84	37.44	3144.96	22.06
39	0	0	0	0.00	0.00	0	0.00	0	0.00	0.00	22.06
40	238	1.8	472	37.16	17539.52	43	1.46	80	37.44	2995.20	22.06

Age	Subsidies												r = 6%
t	SInda-CW	SIda-CW	SIsda-CW	SInda+CW	SIda+CW	SIsda+CW	SUnda-CW	SUda-CW	SUsda-CW	SUnda+CW	SUda+CW	SUsda+CW	df
0	1206.50	1146.50	1086.50	2156.50	2096.50	2036.50	556.50	616.50	616.50	1506.50	1566.50	1566.50	1.0000
1	250.00	190.00	130.00	250.00	190.00	130.00	0.00	60.00	60.00	0.00	60.00	60.00	0.9434
2	250.00	190.00	130.00	250.00	190.00	130.00	0.00	60.00	60.00	0.00	60.00	60.00	0.8900
3	250.00	190.00	130.00	250.00	190.00	130.00	0.00	60.00	60.00	0.00	60.00	60.00	0.8396
4	409.00	349.00	289.00	409.00	349.00	289.00	159.00	219.00	219.00	159.00	219.00	219.00	0.7921
5	250.00	190.00	130.00	250.00	190.00	130.00	0.00	60.00	60.00	0.00	60.00	60.00	0.7473
6	250.00	190.00	130.00	250.00	190.00	130.00	0.00	60.00	60.00	0.00	60.00	60.00	0.7050
7	250.00	190.00	130.00	250.00	190.00	130.00	0.00	60.00	60.00	0.00	60.00	60.00	0.6651
8	250.00	190.00	130.00	250.00	190.00	130.00	0.00	60.00	60.00	0.00	60.00	60.00	0.6274
9	329.50	269.50	209.50	329.50	269.50	209.50	79.50	139.50	139.50	79.50	139.50	139.50	0.5919
10	15.00	15.00	15.00	45.00	45.00	45.00	15.00	15.00	15.00	45.00	45.00	45.00	0.5584
11	15.00	15.00	15.00	45.00	45.00	45.00	15.00	15.00	15.00	45.00	45.00	45.00	0.5268
12	15.00	15.00	15.00	45.00	45.00	45.00	15.00	15.00	15.00	45.00	45.00	45.00	0.4970
13	15.00	15.00	15.00	45.00	45.00	45.00	15.00	15.00	15.00	45.00	45.00	45.00	0.4688
14	15.00	15.00	15.00	45.00	45.00	45.00	15.00	15.00	15.00	45.00	45.00	45.00	0.4423
15	15.00	15.00	15.00	45.00	45.00	45.00	15.00	15.00	15.00	45.00	45.00	45.00	0.4173
16	15.00	15.00	15.00	45.00	45.00	45.00	15.00	15.00	15.00	45.00	45.00	45.00	0.3936
17	15.00	15.00	15.00	45.00	45.00	45.00	15.00	15.00	15.00	45.00	45.00	45.00	0.3714
18	15.00	15.00	15.00	45.00	45.00	45.00	15.00	15.00	15.00	45.00	45.00	45.00	0.3503
19	15.00	15.00	15.00	45.00	45.00	45.00	15.00	15.00	15.00	45.00	45.00	45.00	0.3305
20	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.3118
21	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.2942
22	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.2775
23	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.2618
24	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.2470
25	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.2330
26	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.2198
27	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.2074
28	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.1956
29	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.1846
30	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.1741
31	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.1643
32	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.1550
33	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.1462
34	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.1379
35	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.1301
36	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.1227
37	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.1158
38	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.1092
39	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.1031
40	0.00	0.00	0.00	45.00	45.00	45.00	0.00	0.00	0.00	45.00	45.00	45.00	0.0972

Notes: t = age of stand from planting in year 0

Revenue codes as follows:

M	=	maincrop
T	=	thinnings
trees	=	number of trees
Av Vol	=	average volume per tree (m^3)
Vol/ha	=	volume per hectare (m^3)
price	=	price/m^3 from price-size curve
ben	=	revenue value
costs	=	total annual costs

Subsidy codes as follows:

S	=	subsidy
I	=	planting on improved grassland or arable land
U	=	planting on unimproved land
nda	=	planting is not in a disadvantaged area
da	=	planting in a disadvantaged area
sda	=	planting in a severely disadvantaged area
+CW	=	planting given community woodland grant
-CW	=	planting not given community woodland grant

certain published sources[51]. Assumptions regarding the incorporation of felling and thinning costs within standing timber prices are as before and the full broadleaf cost stream for a typical hectare is detailed in table 6.13.

Table 6.13: Broadleaf plantation costs (£/ha; 1990 prices)[1]

Year from planting	Cost (£/ha)	Cost items
0	740.79	Construct maintenance roads, plough land, other land preparation, initial drainage, new fencing, purchasing plants, individual shelters and stakes (assuming 50% recycling rate), planting, initial fertilizer, initial herbicide.
1	22.06	Maintenance
2	151.81	Beating up, weeding, maintenance
3-5	45.65	Herbicide, maintenance
6-(F-1)	22.06	Maintenance

In addition a cost of £285.03 is incurred in the year before first thinning (varies according to YC) for construction of forwarder roads and transporter points.

Notes: 1. General assumptions are as per table 6.9

Sources: Lewis (pers. comm., 1988), Hart (1987 and pers. comm., 1990).

6.5.3.2: Timber revenues

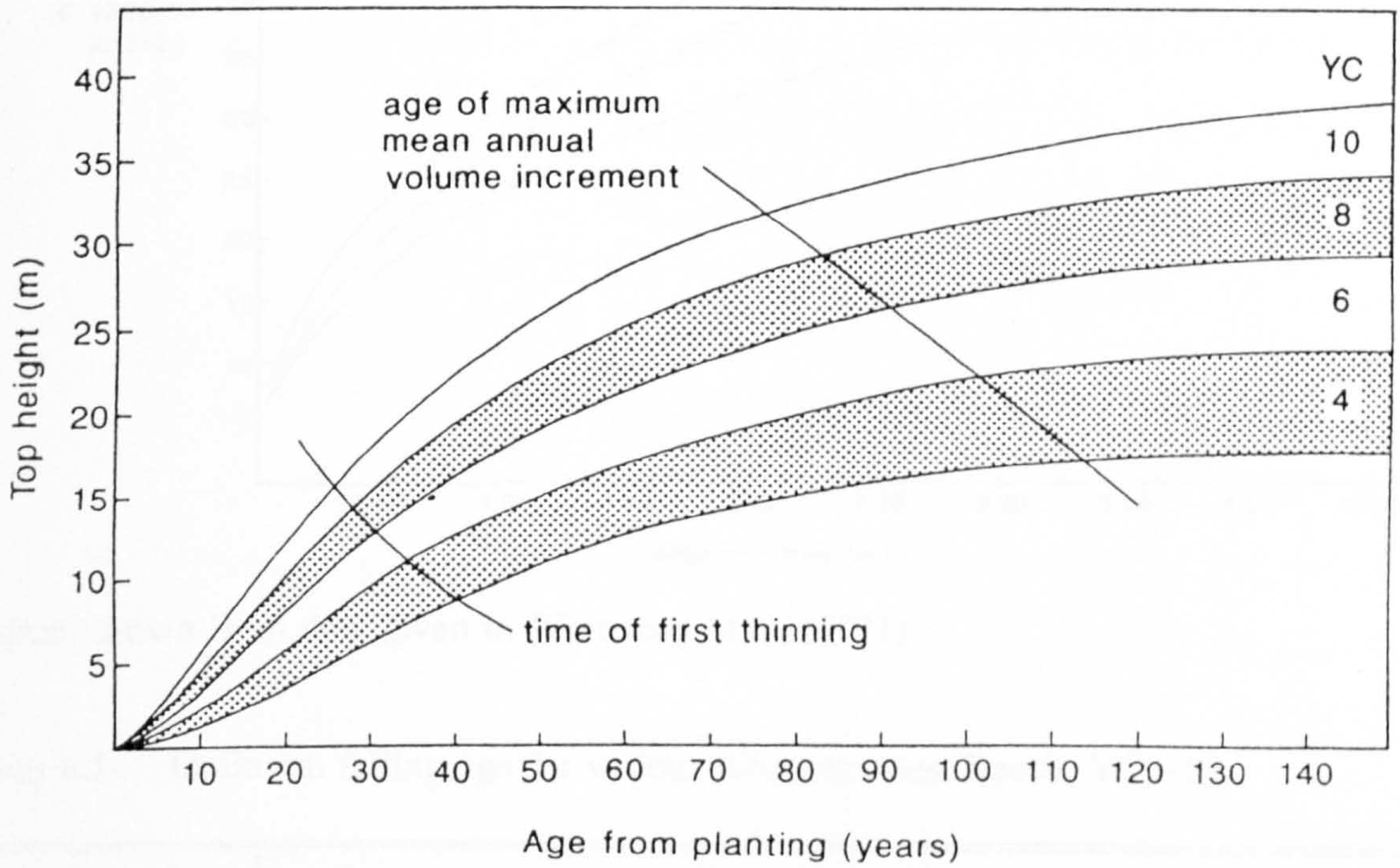
Figure 6.8 details YC curves for beech showing the long rotation periods typical of broadleaved species.

As with conifers, the FC have formalised these YC curves into yield models (Edwards and Christie, 1981) detailing, for all reasonable felling ages, the volume of timber produced at each thinning and at clear-felling. As before price varies positively with tree volume. Furthermore, in their study of price-size curves for broadleaves, Whiteman et al. (1991) show that, because thinnings have relatively high extraction costs per m^3, standing prices for thinnings are on average 24% below the price/m^3 paid for clear fell timber. Consequently two price-size curves are estimated (with a third average curve being reported for ease of

[51]Notably Hart (1987).

generalised account rather than individual plantation assessment). As hardwood timber values vary considerably between species, price-size curves are estimated for each (unlike the generalised conifer relationship), with those for beech being illustrated in figure 6.9.

Figure 6.8: General yield class curves for beech



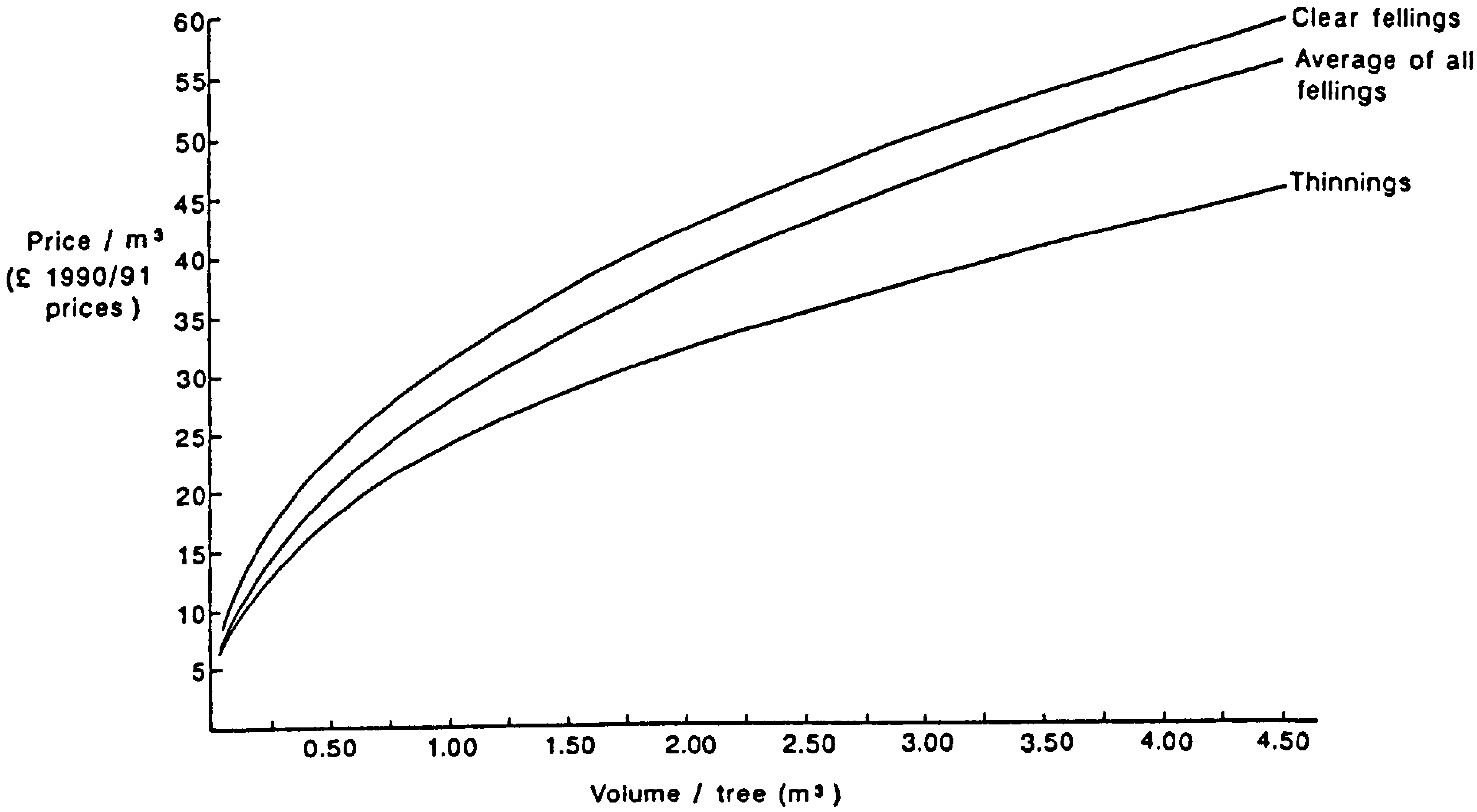
Source: Edwards and Christie (1981)

With volumes and prices established we again simply require the optimal felling age to define the revenue stream. As before this is a function of YC and discount rate and was evaluated using the FIAP software. Table 6.14 details results from this analysis.

6.5.3.3: Timber revenue, subsidy and cost streams

Timber revenues and cost streams were now encoded into the MINITAB software package to allow them to be integrated with available grants and subsidies. Table 6.15 illustrates the resultant database for one yield class/discount rate combination, namely YC10 with a 6% discount rate.

Figure 6.9: Price size curves for beech in Great Britain: 1990/91 prices



Source: drawn from data given in Whiteman et al. (1991)

Table 6.14: Optimum felling age for various discount rates: Beech, YC4-10

Discount rate (%)	Yield Class (beech)			
	4	6	8	10
2	125	120	119	118
3	105	99	95	93
4	91	85	80	78
5	81	75	71	69
6	75	69	65	62
8	65	59	56	53
10	58	52	48	47
12	53	47	43	42

Notes: Optimal felling age maximises NPV given the relevant discount rate (r) and YC combination. The above figures treat the planting year as year 0. The table was calculated using FIAP running at the Forestry Commission Headquarters at Edinburgh (except for the row for r=3% which was interpolated). The author is obliged to Jane Sinclair and Roger Oakes at Edinburgh for assistance.

The table is calculated according to the following assumptions:

Spacing: 1.20 x 1.20
Delay on first thinning: None
Successor crop NPV: Zero
Thinning price differential (£ 1992/93): £0.30 /m³
Thinning: Broadleaved, intermediate thin
Stocking: 85%
Price size curve: Broadleaves for 1989/90 T.R.
Charge per m³ (£ 1992/93): £3.68 /m³

Table 6.15: Revenue (including subsidies) and cost streams for an optimal rotation of YC10 beech with a 6% discount rate: 1990 prices

Age	Maincrop					Thinnings					Costs	Subsidies												r = 6%
t	M.trees	M.AvVol	M.Vol/ha	M.price	M.ben	T.trees	T.AvVol	T.Vol/ha	T.price	T.ben	Costs	SInda-CW	SIda-CW	SIsda-CW	SInda+CW	SIda+CW	SIsda+CW	SUnda-CW	SUda-CW	SUsda-CW	SUnda+CW	SUda+CW	SUsda+CW	df
0	0	0	0	0	0	0	0	0	0	0	740.79	1672.5	1612.5	1552.5	2622.5	2562.5	2502.5	822.5	882.5	882.5	1772.5	1832.5	1832.5	1.0000
1	0	0	0	0	0	0	0	0	0	0	22.06	250	190	130	250	190	130	0	60	60	0	60	60	0.9434
2	0	0	0	0	0	0	0	0	0	0	151.81	250	190	130	250	190	130	0	60	60	0	60	60	0.8900
3	0	0	0	0	0	0	0	0	0	0	45.65	250	190	130	250	190	130	0	60	60	0	60	60	0.8396
4	0	0	0	0	0	0	0	0	0	0	45.65	485	425	365	485	425	365	235	295	295	235	295	295	0.7921
5	0	0	0	0	0	0	0	0	0	0	45.65	250	190	130	250	190	130	0	60	60	0	60	60	0.7473
6	0	0	0	0	0	0	0	0	0	0	22.06	250	190	130	250	190	130	0	60	60	0	60	60	0.7050
7	0	0	0	0	0	0	0	0	0	0	22.06	250	190	130	250	190	130	0	60	60	0	60	60	0.6651
8	0	0	0	0	0	0	0	0	0	0	22.06	250	190	130	250	190	130	0	60	60	0	60	60	0.6274
9	0	0	0	0	0	0	0	0	0	0	22.06	367.5	307.5	247.5	367.5	307.5	247.5	117.5	177.5	177.5	117.5	177.5	177.5	0.5919
10	0	0	0	0	0	0	0	0	0	0	22.06	285	225	165	295	235	175	35	95	95	45	105	105	0.5584
11	0	0	0	0	0	0	0	0	0	0	22.06	285	225	165	295	235	175	35	95	95	45	105	105	0.5268
12	0	0	0	0	0	0	0	0	0	0	22.06	285	225	165	295	235	175	35	95	95	45	105	105	0.4970
13	0	0	0	0	0	0	0	0	0	0	22.06	285	225	165	295	235	175	35	95	95	45	105	105	0.4688
14	0	0	0	0	0	0	0	0	0	0	22.06	285	225	165	295	235	175	35	95	95	45	105	105	0.4423
15	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.4173
16	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.3936
17	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.3714
18	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.3503
19	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.3305
20	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.3118
21	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.2942
22	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.2775
23	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.2618
24	0	0	0	0	0	0	0	0	0	0	329.16	35	35	35	45	45	45	35	35	35	45	45	45	0.2470
25	0	0	0	0	0	1272	0.02	26	4.9	127.4	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.2330
26	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.2198
27	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.2074
28	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.1956
29	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.1846
30	0	0	0	0	0	1062	0.03	35	5.6	196	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.1741
31	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.1643
32	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.1550
33	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.1462
34	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.1379
35	0	0	0	0	0	604	0.06	35	7.1	248.5	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.1301
36	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.1227
37	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.1158
38	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.1092
39	0	0	0	0	0	0	0	0	0	0	22.06	35	35	35	45	45	45	35	35	35	45	45	45	0.1031
40	0	0	0	0	0	351	0.1	35	8.88	310.8	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0972
41	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0917
42	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0865
43	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0816
44	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0770
45	0	0	0	0	0	220	0.16	35	10.9	381.5	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0727
46	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0685
47	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0647
48	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0610
49	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0575
50	0	0	0	0	0	142	0.25	35	13.16	460.6	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0543
51	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0512
52	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0483
53	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0456
54	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0430
55	0	0	0	0	0	98	0.36	35	15.35	537.25	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0406
56	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0383
57	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0361
58	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0341
59	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0321
60	0	0	0	0	0	78	0.5	35	17.73	620.55	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0303
61	0	0	0	0	0	0	0	0	0	0	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0286
62	305	0.92	309	30.19	9328.71	53	0.55	35	18.47	646.45	22.06	0	0	0	45	45	45	0	0	0	45	45	45	0.0270

Notes: t = age of stand from planting in year 0

Revenue codes as follows:

M	=	maincrop
T	=	thinnings
trees	=	number of trees
Av Vol	=	average volume per tree (m^3)
Vol/ha	=	volume per hectare (m^3)
price	=	price/m^3 from price-size curve
ben	=	revenue value
costs	=	total annual costs

Subsidy codes as follows:

S	=	subsidy
I	=	planting on improved grassland or arable land
U	=	planting on unimproved land
nda	=	planting is not in a disadvantaged area
da	=	planting in a disadvantaged area
sda	=	planting in a severely disadvantaged area
+CW	=	planting given community woodland grant
-CW	=	planting not given community woodland grant

6.6: DISCOUNT RATES

Any investment in forestry has to trade off initial costs against delayed benefits. This is conventionally achieved by calculating the NPV of the investment via a discount rate (r), commonly defined in terms of two elements: pure time preference; and the opportunity cost of capital. Adopting the notation of Pearce and Ulph (1995) we have the standard discount rate equation as follows[52]:

$$r = \delta + \mu g \qquad (6.3)$$

where:

r = discount rate

δ = time preference rate (the rate at which utility is discounted)

μ = elasticity of the marginal utility of consumption schedule

g = expected growth rate of average consumption per capita.

This research has set out to examine two perspectives regarding the decision about

[52]For a good introduction see Pearce (1986) and for further reading see Pearce and Nash (1981), Lind (1982a,b) and Price (1993), the latter being of particular relevance to forestry.

whether or not agricultural land should be converted to forestry: that of the farmer; and that of society. However, there is good reason to suppose that these two will have differing discount rates[53]. Put at its simplest, if we consider time preference, farmers are mortal while society is, at very least, much longer lived (we hope!). Therefore society is likely to be more concerned about long delayed returns than will an individual farmer. Accordingly we might expect society to have a relatively lower rate of pure time preference. A similar result is obtained when we consider the opportunity cost of capital basis for discounting. For a risk-averse society this should imply a relatively low social discount rate dictated by the rate of return on riskless investments (government bonds, etc). However, for the private individual the opportunity cost of capital should be relatively high due to the rates of return available from alternative investments[54].

In this section we examine evidence regarding agricultural and social real[55] rates of discount. However, before turning to this we need to address one further complication, that of the comparability of agricultural and forestry investments. Farmers commonly make decisions on an annual timescale whereas the time horizon of a forester is usually a full rotation of a stand, which typically varies from a minimum of four decades for conifers to over a century for hardwoods. Comparison of annual gross margin with rotation NPV is therefore problematic. Two approaches exist. Firstly agricultural margins could be assessed and discounted over a rotation length. Secondly, woodland NPV can be converted to an annual equivalent, i.e. the constant annual return (or 'annuity') which, over the length of a rotation, would be valued equally with the standard NPV sum. After discussion with relevant experts[56] it was decided that the former option lacked credibility as farmers (who are the relevant decisionmakers) are used to annual rather than rotational decisionmaking. Therefore, after calculating NPV's for all our yield models (using the relevant agricultural or social discount rate), these were converted to annuity equivalents using the formula given as equation (6.4).

[53]For further discussion on the divergence of social from private discount rates see Baumol (1968), Goodin (1982), Sen (1982), Sagoff (1988) and Pearce and Turner (1990).

[54]This may be a less strong argument if re-investment is restricted to the agricultural sector where rates of return are historically low.

[55]ie. inflation adjusted as opposed to nominal (unadjusted) discount rates.

[56]Notably Colin Price and Rob Willis, UCNW, Bangor.

$$\text{Annuity} = \left\{ \frac{(1+r)^F}{[(1+r)^F]-1} * \text{NPV} \right\} * r \qquad (6.4)$$

where:

r	=	discount rate (expressed as decimal, e.g. 6% rate expressed as 0.06)
F	=	felling year (length of optimal rotation, in years)
NPV	=	net present value calculated for discount rate r and optimal felling year F
{ . }	=	net present value of an infinite sum of optimal rotations.

6.6.1: FARMERS' DISCOUNT RATES

6.6.1.1: Literature review

A priori we would expect that the relatively lower rates of return exhibited by the agricultural sector (as opposed to industrial and commercial equivalents) would result in somewhat lower real discount rates than the government's 8% estimate for the rest of the private sector (H.M. Treasury, 1991)[57]. However, little explicit work has been published in this area with most commentators examining real rates of return or agricultural interest rates rather than discount rates per se.

The early work in this latter area is predominantly American, dating back to Melichar (1979) who proposed that real rates of return were determined by expected rents and actual and expected inflation rates. Feldstein (1980) modified this theory by suggesting that such a mechanism may ultimately be driven by inflation acting upon land prices, while Tanzi (1980) extends this by proposing a further link to the business cycle. However, in an empirical test of these theories, Alston (1986) failed to find a long-run link between inflation and land prices and Burt (1986) rejects such complex models in favour of a simple long run equilibrium land price approach which yields a real rate of return estimate of 4% per annum.

Similar results are reported by Cooper (1992) who uses a real interest rate approach based on the work of Brase and La Due (1989), to report a mean value of 4.5% for UK agriculture for the period 1964-90. While agricultural interest rates are highly variable[58], such a result seems to be roughly echoed by current lending practice. In correspondence with

[57]The 8% estimate is "based on average returns on assets achieved in the private sector for activities with low cyclical year by year variability" (H.M. Treasury, 1991). Rates are expected to be higher in other areas of the private sector.

[58]Annual averages range from -13.01% (1976) to +10.08% (1990) in Cooper (1992).

the author the National Westminster Agricultural Office[59] (a major source of farm finance) quote an average real agricultural interest rate of 4% over base rates which in turn roughly shadow inflation rates (at present).

A lower interest rate, averaging 2.44% above base rate, is reported by Cunningham (1990) in a study of MAFF surveys, while MAFF themselves currently assume an agricultural interest rate risk premium of 2.78% above base rate[60]. However, there are several problems with extrapolating from interest rates to discount. Firstly, if base rates fluctuate frequently, lags in the adjustment system may confound the analyst. Secondly, interest rates vary very significantly across farms, projects and time[61]. Thirdly, the link between interest rates and discount rates may be weak in that the former relate to returns on new investments rather than on total assets (which are likely to be lower).

In addressing this latter point, Harrison and Tranter (1989) analyse the period 1978/79 to 1986/87, reporting a mean real rate of return on all assets of 2.56%[62]. Positive time preference would suggest that the real discount rate might be somewhat higher than this, a factor which gives further support to the findings of a recent study by Lloyd (1993). Here a capital asset pricing model of agricultural land prices in England and Wales for the period 1946-89 is used to empirically derive a long run real discount rate of 3.6%.

These latter studies provide what we feel is the best evidence on agricultural real discount rates. However, neither study is specific to our Welsh study area and so our own rate of return analysis was undertaken.

6.6.1.2: Empirical work

Two studies of agricultural rates of return in Wales were undertaken; the first being a short time-series analysis of the period 1987-92; the second being a cross sectional study of the 1989/90 base year. In both cases data was provided by the Welsh division of the Farm

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[59]Pers. comm. Sue Train, NWAO, and letters from Brian Montgomery, Senior Executive, NWAO, July 1993. However, this correspondence highlighted the variation in rates across farms and projects. For example a range of real rates from 0-5% was given for differing projects and times by Charles Morgan of Chris Grote Farms, Norfolk.

[60]Pers. comm. Douglas Cooper, MAFF, 1993.

[61]This point was made in correspondence with both NWAO (see above) and Paul Hill (Wye College) who stated that while interest rates were roughly 2% above base rates for good risks, they could be very much higher for risky investments.

[62]Sample extends across Great Britain. Rates are quite consistent only ranging from 1.87% to 3.90%.

Business Survey[63] (FBS, 1988, 1989, 1990, 1991, 1992) which defines the nominal return as farm income expressed as a percentage of tenants capital[64].

i. Rates of return in Wales: 1987-92

Table 6.16 details nominal rate of return (RoR_n) statistics for various categories of farm type identified during FBS surveys for the years 1987/88 to 1991/92. These categories are further subdivided by farm size.

Statistical analysis was undertaken across all farm categories except those for pig and poultry, and cropping farms as these are minor activities in Wales and were not separately classified after 1989. This showed that specialist or mainly dairy farms achieved significantly higher RoR_n than did other farms. Subsequent analysis also isolated a quadratic relationship with size (measured in BSU[65]) showing that RoR_n rose with size but at a diminishing marginal rate. RoR_n also fluctuated annually although only one year (1988/89) was found to be significantly different from all others[66].

A model was constructed encapsulating these relationships and was tested across a variety of functional forms. Our best fitting model is reported as equation (6.5). Tests for multicollinearity, autocorrelation and heteroscedasticity failed to isolate any significant problems with this model.

$$RoR_n = \underset{(-9.06)}{-\,18.616} + \underset{(6.32)}{7.683}\ TYPE + \underset{(6.53)}{9.566}\ HIYEAR + \underset{(8.38)}{1.1289}\ BSU_t - \underset{(-6.33)}{0.010508}\ BSU_t^2 \qquad (6.5)$$

where

RoR_n	=	nominal net rate of return on tenants capital (%)
TYPE	=	1 for dairy farms (FBS specialist or mainly dairy categories)
	=	0 for non dairy farms (other categories)

63 The FBS is an arm of MAFF (operating in Wales under the auspices of the Welsh Office) which conducts annual surveys of a representative sample of farms throughout the country. Sample size averaged 734 farms per annum over our 1987-92 study period, however, many farms are retained in the sample for about 3 years. The number of unique farms in the time series is 2867.

64 Definitions are as follows (from FBS, 1989): The farm management and investment income (MII), which represents "the reward for the farmer's (and spouse's) management and interest on the tenant's capital employed on the farm", is given by the difference between farm output and input values (the latter including both actual and notional income for the labour of the farmer and spouse); Tenant's capital (K_F) is defined as "the value of livestock, machinery, crops (including cultivations) and stores .... expressed as the average of the opening and closing valuations for these items"; Return on tenant's capital is therefore [(MII/K_F) x 100].

65 British stocking units.

66 Interaction terms were found to be insignificant.

HIYEAR = 1 for 1988/89

= 0 otherwise

BSU_t = Average size of farm type in year t where, here, farmtype is:

$$\left.\begin{array}{l}1 = \text{Specialist dairy}\\ 2 = \text{Mainly dairy}\end{array}\right\}\ \text{1 in TYPE dummy}$$

$$\left.\begin{array}{l}3 = \text{Hill sheep}\\ 4 = \text{Hill cattle and sheep}\\ 5 = \text{Upland cattle and sheep}\\ 6 = \text{Lowland cattle and sheep}\end{array}\right\}\ \text{0 in TYPE dummy}$$

BSU_t^2 = $BSU_t * BSU_t$

R^2 = 77.9%

$\bar{R}^2$ = 76.7%

F = 66.10

p = 0.000

dw = 1.89 where $\left.\begin{array}{l}d_L = 1.39\\ d_u = 1.60\end{array}\right\}$ n = 79; exp. vars. = 4 $\Big\}\therefore$ no autocorrelation

Note: numbers in brackets are t-values

Average RoR_n for dairy and non-dairy farms (denoted RoR_n^D and RoR_n^{ND} respectively) over the study period can now be evaluated by substituting each group's mean values for explanatory variables[67] into equation (6.5). For dairy farms this yields equation (6.6)[68]:

$$\begin{aligned} RoR_n^D = & -18.616 + 7.683(1) + 9.566(0.2) \\ & + 1.1289(34.02) - 0.010508(1590) \\ = & \ 12.677658 \\ = & \ 12.68\% \end{aligned} \tag{6.6}$$

For non-dairy farms this yields equation (6.7)

$$\begin{aligned} RoR_n^{ND} = & -18.616 + 7.683(0) + 9.566(0.2) \\ & + 1.1289(24.78) - 0.010508(918) \\ = & \ 1.624998 \\ = & \ 1.62\% \end{aligned} \tag{6.7}$$

As can be seen, simple analysis of RoR_n shows that they vary dramatically across farms. The difference between dairy and non-dairy farms is highly significant indicting the

[67]Means were used after examining variable distributions for skewness. Arguably mean values may not reflect conditions on optimal sized farms however this is an analysis of actual rather than optimal farms.

[68]Note that the average for the BSU_t^2 term is data derived and consequently slightly differs from the square of the BSU_t mean.

very considerable positive impact which CAP milk quotas have had upon dairy farm incomes.

Table 6.16: Agricultural nominal rate of return on tenants capital: Wales 1987/88 - 1991/92

Farm type and size	1987/88 n	1987/88 mean size (BSU)	1987/88 rate (%)	1988/89 n	1988/89 mean size (BSU)	1988/89 rate (%)	1989/90 n	1989/90 mean size (BSU)	1989/90 rate (%)	1990/91 n	1990/91 mean size (BSU)	1990/91 rate (%)	1991/92 n	1991/92 mean size (BSU)	1991/92 rate (%)	1987-92 n	1987-92 mean size (BSU)	1987-92 rate (%)
Specialist Dairy																		
Up to 15.9 BSU	30	11.87	10.04	30	11.85	13.89	28	11.37	4.84	20	10.42	-0.13	17	10.15	-6.25	125	11.29	5.9566
16-23.9 BSU	26	19.57	10.21	26	19.32	13.02	18	19.98	14.29	14	19.27	4.27	20	19.48	9.27	104	19.52	10.6383
24-39.9 BSU	35	30.82	13.76	35	31.23	26.52	38	30.95	17.81	34	31.63	13.30	28	31.13	15.24	170	31.15	17.4441
40 BSU and over	27	67.13	25.10	27	69.03	36.06	31	67.10	27.37	36	63.21	19.69	31	60.70	20.65	152	65.22	25.3209
All sizes	118	31.83	18.11	118	32.33	27.77	115	34.21	21.16	104	36.82	15.56	96	34.54	16.25	551	33.85	20.0099
Mainly Dairy																		
Up to 23.9 BSU	14	14.14	6.65	14	14.14	4.78	14	15.38	0.01	25	16.31	-1.12	15	14.15	-2.99	82	15.02	1.0648
24-39.9 BSU	15	31.45	13.41	15	31.79	18.32	13	31.91	13.72	9	34.61	13.60	11	34.52	13.68	63	32.61	14.7173
40 BSU and over	18	56.08	15.55	18	54.48	19.36	18	59.89	16.08	15	73.32	10.05	16	72.21	13.70	85	62.63	15.1502
All sizes	47	35.73	13.83	47	36.37	17.31	45	37.96	13.24	49	37.12	8.11	42	41.20	11.67	230	37.59	12.8127
Hill Sheep																		
Up to 15.9 BSU	24	10.13	-3.84	24	10.55	1.34	25	10.03	-18.04	22	9.69	-16.54	21	11.36	-3.15	116	10.33	-8.1123
16 BSU and over	27	32.57	13.96	27	31.67	20.06	24	33.68	6.14	32	31.14	-1.04	32	34.28	11.14	142	32.65	9.7824
All sizes	51	22.01	10.14	51	21.73	15.99	49	21.62	0.54	54	22.40	-3.84	53	25.20	8.76	258	22.62	6.2636
Hill Cattle & Sheep																		
Up to 15.9 BSU	39	10.30	3.91	39	10.64	9.49	35	10.87	-8.81	34	11.52	-11.80	25	10.44	-5.86	172	10.75	-1.9387
16-23.9 BSU	29	19.07	5.58	29	19.52	12.21	32	18.87	-2.55	36	19.65	-4.06	23	19.99	4.70	149	19.40	2.6594
24-39.9 BSU	26	30.14	12.87	26	30.33	17.70	28	29.82	5.72	29	31.37	2.57	25	31.41	8.29	134	30.61	9.2296
40 BSU and over	14	57.77	20.84	14	57.36	20.12	15	70.36	7.22	18	76.13	-3.53	20	74.04	6.70	81	68.13	9.2864
All sizes	108	23.59	12.11	108	23.82	15.85	110	26.13	2.38	117	28.88	-2.85	93	32.12	5.37	536	26.79	6.4318
Upland Cattle & Sheep																		
Up to 15.9 BSU	16	9.33	-3.66	16	8.65	3.53	16	9.29	-7.42	19	8.29	-17.65	19	7.56	-15.09	86	8.58	-8.6379
16 BSU and over	20	26.21	4.64	20	27.43	7.52	18	23.29	-2.07	23	25.66	-3.53	25	30.43	2.14	106	26.82	1.6816
All sizes	36	18.71	2.71	36	19.08	6.60	34	16.70	-3.57	42	17.80	-6.57	44	20.55	-0.81	192	18.65	-0.5094
Lowland Cattle & Sheep																		
All sizes	13	12.64	-1.50	13	12.68	1.38	17	18.14	-5.05	31	22.84	-1.59	26	17.90	-0.06	100	18.11	-1.3826
Pig and Poultry																		
All sizes	6	29.77	3.96	6	22.64	12.94	*	*	*	*	*	*	*	*	*	12	26.20	8.4500
Cropping Farms																		
All sizes	11	44.84	10.96	11	42.89	1.54	*	*	*	*	*	*	*	*	*	22	43.87	6.2500
Summary statistics[1]																		
Total	750			750			723			763			682			3668		
Mean		28.07	9.54		27.81	14.06		28.45	4.91		29.91	0.61		30.16	5.40		29.23	7.07
Trimmed Mean		27.11	9.43		26.75	13.61		27.26	4.93		28.61	0.57		29.04	5.67		28.37	6.95
Standard Deviation		15.92	7.40		15.93	8.99		17.85	11.17		19.40	10.03		18.98	8.94		17.05	8.45
S.E. Mean		3.32	1.54		3.32	1.87		3.90	2.44		4.23	2.19		4.14	1.95		3.56	1.76
Minimum		9.33	-3.84		8.65	1.34		9.29	-18.04		8.29	-17.65		7.56	-15.09		8.58	-8.64
Lower Quartile		14.14	3.96		14.14	6.60		16.04	-3.06		17.06	-3.95		16.02	-1.90		18.11	1.06
Upper Quartile		32.57	13.83		32.33	19.36		33.94	14.01		35.72	9.08		34.53	12.68		33.85	12.81
Maximum		67.13	25.10		69.03	36.06		70.36	27.37		76.13	19.69		74.04	20.65		68.13	25.32

Notes:

1. The summary statistics are calculated by omitting the "All sizes" category means (except where this is the only entry for the category).
2. The 1987-92 mean rate of return is weighted by annual numbers of farms as is the average BSU size
3. * = not available
4. n = number of farms in sample
5. rate = nominal rate of net return on tenants capital, calculated as follows:

MII = Output - Inputs

and rate = (MII/TC) * 100

where:

(i) Output = All returns from an enterprise, plus the market value of any of its products transferred out to another enterprise, plus the market value of any production from the enterprise given to workers or consumed on the farm. In the case of livestock enterprises, the value of purchased livestock and the market value of livestock transferred in from another enterprise are deducted. All totals are adjusted for changes in valuation.

(ii) Inputs = Feeds (purchased concentrates, homegrown concentrates, purchased bulk) + Tack and stock keep + veterinary and medicines + other livestock costs + fertilisers + seeds (purchased and homegrown) + other crop costs + labour (farmer and spouse, paid, unpaid, casual) + machinery (contract, repairs, fuels, depreciation) + general farming costs + other land expenses + rent/rental value + rates.

Note that as a nominal farmer/spouse labour cost is included, we are calculating net rather than gross returns.

(iii) MII = Management and Investment Income; The MII represents the reward for the farmer's (and spouse's) management and interest on the tenants capital employed on the farm

(iv) TC = Tenants Capital; The value of livestock, machinery, crops (including cultivations) and stores. In the Farm Business Survey tables, tenants capital is expressed as the average of the opening and closing valuations for these items.

Sources: data taken from FBS (1988, 1989, 1990, 1991, 1992)

Conversion to real rates of return (RoR_r) was achieved using retail price indices[69] given in CSO (1993). This shows an average inflation rate for the period 1987-92 of 5.81% implying $RoR_r^D = 6.86\%$; and $RoR_r^{ND} = -4.18\%$.

One problem with our approach is that it uses mean BSU by farm type (dairy or non-dairy), yet the summary statistics given in table 6.16 suggest that the distribution of farm sizes is positively skewed (mean significantly exceeds trimmed mean) rather than normal. An alternative approach is to simply examine the mean rates of return weighted by the number of farms in each category. This gives equal weight to all farms irrespective of their size. Table 6.17 reports RoR_n and RoR_r for each of the farm categories shown in table 6.16 with real rates adjusted from nominal as before.

Table 6.17: Mean nominal and real rates of return on tenants capital: Wales 1987/88-1991/92

Farm type	n	mean nominal rate of return RoR_n (%)	mean real rate of return RoR_r (%)
Specialist dairy	551	15.73	9.92
Mainly dairy	230	10.01	4.20
All dairy	781	14.04	8.24
Hill sheep	258	1.74	-4.07
Hill cattle and sheep	536	3.83	-1.98
Upland cattle and sheep	192	-2.94	-8.75
Lowland cattle and sheep	100	-1.38	-7.19
All cattle and sheep	1086	1.65	-4.15

Source: data taken from FBS (1988, 1989, 1990, 1991, 1992)

Comparison of results from table 6.17 with estimates from equations (6.6) and (6.7) show that treating all farms equally produces similar results to those obtained when farm size is considered, particularly in the case of non-dairy farms.

ii. Rates of return in Wales: 1989/90

We were particularly interested in RoR_n during our study base year. The previous

[69]Use of the RPI rather than some farm price index reflects the fact that ultimately investment funds could be moved out of the agricultural sector.

analysis suggests that this is not a significantly unusual year and should therefore be fairly representative. Furthermore, given that the previous 1987-92 time series included one exceptionally good year (1988/89), we might expect the five year average from that study to be somewhat about that observed in 1989/90.

In addition to the previous TYPE and BSU variables, a number of farm level variables (e.g. capitalization, livestock intensity, etc) were analysed. These were taken from the FBS individual farm record database and are discussed in further detail in chapter 9. These data permitted a superior definition of the TYPE variable. The redefined variable (MILK) showed that any farm with at least 20% of farm output derived from dairy produce had a significantly higher RoR_n than other non-dairy farms. However, no further significant, non-collinear, farm output variables were defined.

A number of physical environment variables (e.g. soil type, altitude, etc) were also investigated. These were obtained from the LandIS database of the Soil Survey and Land Research Centre, Cranfield (discussed in detail in chapter 7). However, no variables could be introduced into the model without inducing severe collinearity problems. Finally a regional variable derived from the work of Rudeforth et al. (1984) was tested and found to be insignificant at the $\alpha = 10\%$ level. The final model is therefore similar to that derived in our previous analysis and is given as equation (6.8):

$$RoR_n = \underset{(-9.66)}{-39.372} + \underset{(9.51)}{13.205 \ln BSU} + 12.115\ TYPE \tag{6.8}$$

$R^2 = 43.3\%$ $\qquad$ $\bar{R}^2 = 42.8\%$ $\qquad$ $n = 240$

Where:

RoR_n = nominal rate of return 1989/90
BSU = farm size in BSU
TYPE = 1 if Dairy
0 is Non-Dairy

Note: 'Non-Dairy' is defined as less than 20% of farm output being milk [n (non-dairy) = 126 of which 124 had zero milk revenue; 1 had 3% milk revenue and 1 had 7% milk revenue; (next farm had 24% milk revenue)].

Substituting variable means into equation (6.8) allows us to calculate the RoR_n for dairy and non-dairy farms, given as equations (6.9) and (6.10) respectively.

$$\begin{aligned} RoR_n^D &= -39.372 + 13.205(3.2208) + 12.115(1) \qquad (6.9)\\ &= 15.273664 \\ &= 15.27\% \end{aligned}$$

$$\begin{aligned} RoR_n^{ND} &= -39.372 + 13.205(2.7773) + 12.115(0) \qquad (6.10)\\ &= -2.6977535 \\ &= -2.70\% \end{aligned}$$

Adjusting for inflation (which averaged over 9% in 1989/90) implies $RoR_r^D = 5.81\%$ and $RoR_r^{ND} = -12.2\%$. These results emphasize our previous conclusions regarding the gulf between dairy and non-dairy farms in Wales. Indeed here we see the latter group even making negative nominal rates of return, a situation which is clearly non-sustainable in the long run.

6.6.1.3: Farm discount rates: summary

While data is scarce, available information suggests that agricultural discount rates will be low relative to other sectors of the economy. Our literature survey suggests that general rates as low as 3% in real terms are quite defensible. However, our analysis of rates of return highlights the great variability which exists between the performance of different sections of the agricultural community and in particular, with reference to Wales, the disparity between dairy and non-dairy farms. As table 6.16 indicates, the elite of dairy farms consistently record nominal (and sometimes real) rates of return in double figures, while, as our subsequent analyses highlight, Welsh non-dairy farms regularly show negative real rates of return. These latter rates are clearly non sustainable in the long term and the exodus from Welsh hill farming consistently observed over recent years (FBS 1987-1992) seems set to continue. That said, those farms which remain in business must, by definition record positive (if low) rates of return and have positive discount rates.

The link between rates of return and discount rates is not simple involving as it does consideration of time preference. This may raise discount rates above rates of return although consideration of studies such as Lloyd (1993) suggest that this will not be by a particularly large amount. In the case of dairy farms we feel that rates of 12% and 6%[70] should provide

[70] Arguably our findings could support a slightly higher rate. However, as discussed in the following section, choice of a 6% rate is useful for comparative purposes as this is the government's discount rate for non-commercial and/or low risk activities.

respectively an upper bound and majority best estimate of real discount rates for Welsh dairy farms. For non-dairy farms rates will clearly be significantly lower with only the most efficient aspiring to the 6% rates. After consideration of our literature review, empirical analyses and the non-sustainability of negative rates of return, we feel a real discount rates sensitivity range from 1.5% to 3% should be appropriate for those non-dairy Welsh farms which do survive into the next century.

6.6.2: SOCIAL DISCOUNT RATES

The Thatcherite assertion (implicit in much positive economics) that society is no more than the sum of its individuals suggests that we should not separate out social and private discount rates. However, upon closer examination we can see that social preference often diverges from individual preference. As Fankhauser (1993) puts it:

> "Drug legislation, safety regulations, speed limits or state pension schemes are all examples of a paternalistic state ignoring individual preferences".

Pearce and Turner (1990) seem to argue that the individual may contain two separate and at times conflicting preference maps: the private and the public. The optimal decisions, time-horizons and therefore discount rates of these preference systems may be very different[71]. Recognition of such a divergence in part underlies the difference between the Treasury's 'required rate of return' for 'commercial' investments of 8% and its 'public service output' discount rate of 6% (H.M. Treasury, 1991).

An important exception to this rule is the land acquisitions and new planting activities of the Forestry Enterprise arm of the Forestry Commission. Here a 3% discount rate is allowed. However, it is important to note that this is not as a result of any notion of public preference being different for the benefits of forestry, but rather as a subsidy so that the official rate of 6% can, on paper, be obtained. This rather absurd accountancy sleight of hand comes about from the simple reason that, if a 6% rate were rigorously enforced, almost no

[71]For example, with respect to transport my private preference may be to drive unimpeded upon open roads from my home to place of work, while my public preference recognises to externality cost of the former option and prefers a reliable, widely available, public transport system. Where this internal conflict is not resolved we see NIMBYism.

new planting would occur. By using a 3% rate some (although by historical standards comparatively little) planting does pass a simple benefit-cost test and the shortfall between revenue generated by this planting and that necessary to satisfy a 6% discount rate is written off as Forest Subsidy[72].

We have argued elsewhere (Henderson and Bateman, 1993) that a comparatively lower discount rate for forestry may be justified on the grounds of true social preference, and that, as the time horizons underlying such preferences vary across projects, so we would expect society to have multiple discount rates. The Treasury's unwillingness to admit such a possibility (evidenced by the farcical cooking-the-books which is the Forestry Subsidy), arises, quite understandably, from the decisionmaking horror of having to choose between projects which are discounted differently (nevertheless we feel that the complexity of social preferences does imply multiple discount rates and return to this subsequently). Consequently the Treasury's public service discount rate is derived from empirical data averaged over a wide variety of sectors (and we would argue, a wide discrepancy of social preferences). This rate is calculated from values of roughly 2 for each of the elements of the basic discount rate formula (equation (6.3)), i.e. $r = \delta + \mu g = 2 + (2 * 2) = 6\%$. However, a wide variety of views exist regarding the value of each of these elements.

Perhaps most controversial is the value of δ, the pure rate of time preference in the social discount rate (r_s). If society is immortal (or aspires to be) then, as very many eminent commentators have pointed out, δ should be very low or zero (Ramsey, 1928; Pigou, 1932; Solow, 1974, 1992; Price, 1987, 1993; Cline, 1992, 1993; Broome, 1992; Fankhauser, 1993, 1995; Pearce and Ulph, 1995; Arrow et al., forthcoming). Such arguments have been reinforced by the debate surrounding sustainable development. This has centred upon notions of Rawlsian equity (Rawls, 1972) wherein, to be truly equitable, decisions regarding the use of resources (be they involving man-made, human or natural capital)[73] should be made behind a 'veil of ignorance' with respect to their temporal impact. Such a view is fundamental to the often quoted Brundtland Commission definition of sustainable

[72]The detail of the situation is more bizarre than this. As all the Forestry Commission's historical felling decisions were made at a 5% discount rate this has been retained. The Commission therefore has rates of 3%, 5% and 6% applied to different areas of its operation.

[73]For an excellent overview of the key role of capital types in notions of sustainability see Pearce et al., (1989) or Turner and Pearce (1993). While radical from an NeoClassical perspective, more extreme (but very interesting) views are given in the work of Herman Daly (Daly, 1977; Daly and Cobb, 1990).

development as "... development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Price (1993) sees this as only interpretable as an abandonment of discounting for global level social decisionmaking.

A more 'conventional' view is given by Fankhauser (1993) who sees the above as implying that $\delta = 0\%$, but not necessarily that $r_s = 0\%$. Pearce and Ulph (1995) review an extensive literature on social δ reporting a range from 0 - 1.7% but favouring (for empirical reasons) a relatively high best estimate of $\delta = 1.4\%$.

Turning to consider the elasticity of the marginal utility of consumption (μ) Price (1993) reports a wide divergence of private sector rates, generally ranging from 0.5 (Squire and van der Tak, 1975)[74] to 3 (Little and Mirlees, 1974). Stern (1977)[75] finds many values in the region of 2, however, we would expect the social preference value of μ to be somewhat lower than that found in the market. This is borne out by Pearce and Ulph (1995) who report a best estimate of social μ of 0.8 with a range from 0.7-1.5.

The social value of g (the expected rate of growth of average consumption per capita) is typically taken as being the real rate of growth of national income. Following such an approach, Lind (1982a,b) argues for a maximum rate of $g = 2\%$[76]. However, the sustainable development debate has highlighted the problem that accounting measures such as GDP often ignore changes (frequently losses) in the natural and other non-market capital base of the economy (Repetto et al., 1989[77]). Taking account of these Pearce and Ulph (1995) suggest a best estimate for g in the UK of 1.3% with a range from 1.3-2.2%.

Taking best estimates from Pearce and Ulph (1995) gives a central estimate of r_s for the UK of about 2.4% (= 1.4 + [0.8 * 1.3]) with a range from 0.9-5%. While this may seem low with respect to the Treasury's rate[78] it is higher than that recently put forward by certain

[74] μ is negative but we report modulus values following the convention of Pearce and Ulph (1995).

[75] Stern (1977) reports one extreme value of $\mu = 10$.

[76] Turner et al. (1994) point out that real growth in GDP in less developed countries is often much lower than this and sometime negative.

[77] Repetto puts forward an adjusted, sustainable national income measure. See also Pearce et al. (1989), Pearce and Warford (1992) and Pearce (1993).

[78] Pearce and Ulph suggest that for policy purposes the Treasury should use a range from 2-4%. In conversation with the author (November, 1994), David Pearce stated that in meetings with the Treasury they had accepted the validity of such figures, but had stated that for policy reasons they would not be adopted. This is perhaps the most damning evidence of official rates being dictated by policy rather than preferences. Henderson and Bateman (1993) show that such political rigging of discount rates is far from exclusive to the UK.

other commentators, particularly with respect to the discounting of global warming damages (perhaps the most potent challenge to intergenerational equity in the history of man). While not stating any particular rate, Arrow et al. (forthcoming) do make explicit reference to the range from 0-2% used by Cline (1992) in his economic analysis of long-run climate change models. Similarly, in his evaluation of the social costs of greenhouse gas emissions, Fankhauser (1993) uses a central (mode) estimate of $r_s = 0.5\%$ with a range from 0-3% (the upper end being mainly for comparative purposes with other studies[79]).

A further complication arises from the issue of multiple discount rates; the notion that social preferences may diverge radically between projects to the extent that a single discount rate is somewhat of an over-simplification. As Arrow et al. (forthcoming) and many earlier commentators have pointed out, the key factor here is substitutability, i.e. the extent to which development benefits (often in terms of man-made capital, K_m) be traded off against costs (generally in terms of natural capital, K_n). Assuming for the moment that sustainability is socially desirable and that both sets of capital can be measured in some comparable numeraire (presumably money), then perfect substitutability would mean that any project would simply have to pass a standard Hicks-Kaldor hypothetical compensation test[80] to be sanctioned. In the literature of sustainable development this has been termed the 'very weak sustainability' rule (Turner and Pearce, 1993) which states that, provided total net benefits (total capital) are non-declining, a project may be sanctioned. This perfect substitutability assumption may be more acceptable for some K_m/K_n swops (e.g. Sitka spruce plantations into paper thence into money and so back to new plantations) than for others (e.g. the destruction of SSSI's to make way for motorways[81]), i.e. some K_n destruction is irreversible.

Bateman (1991) suggests that we can define a continuum of capital types from money (the purest form of K_m) through various types of K_n (trees, land, etc) to 'critical natural capital' (K_n^c),[82] the latter being those services of the planet vital to life-support (climate and atmosphere control, ozone layer, etc). As we move away from money along this continuum, so the potential for substitution, rather than staying constant, falls until it reaches zero with K_n^c.

[79]For example Nordhaus (1991a,b,c).
[80]See almost any cost-benefit text, for example, Pearce (1986).
[81]As in the case of the M3 Twyford Down extension.
[82]The term is borrowed from Pearce and Turner (1990).

Such a view causes problems for cost benefit analysis if we feel that the building up of K_m does not adequately compensate for the loss of K_n. This is the view of the 'weak sustainability' rule (Turner and Pearce, 1993) which argues that stocks of K_n^c should be inviolate, while K_n should be subject to some safe-minimum-standard (SMS), below which use should be prohibited[83]. A further interpretation, the 'strong-sustainability' rule, in effect argues that such a SMS has already been breached and that any further use of K_n should be offset by actual physical compensation in terms of shadow projects restoring, transplanting or recreating levels of any K_n used in future projects[84].

The divergence between best estimates of r_s given by Pearce and Ulph ($r_s = 2.4\%$) and Fankhauser (0.5%) or Arrow et al. (implicitly 0-2%) can therefore be viewed as comparing a general rate of K_m/K_n substitutability with that of a non-substitutable good: global climate. The implication of such an analysis is that, because of the various rates of substitutability and irreversibility inherent in the differing capital base of each project, society will have different discount rates for different projects. Furthermore, we could extend this line of reasoning to the individual costs and benefits of a single project so that, in our forestry case study, UK timber (for which losses are reasonably reversible) might attract a higher r_s than recreation benefits (which arguably belong to a more depleted set of K_n), which is more discounted than carbon storage (which contributes to the K_n^c stock of global climate services). Following this argument in our final analysis of results we examine the impact of using multiple discount rates in our forestry case study.

In practice, the variance of r_s within a project is clearly a decisionmaking nightmare and opens up the potential for discount rate 'management' abuses. Indeed the avoidance of abuse may be the most coherent argument for adopting a single rate policy. In a review, Henderson and Bateman (1993) report numerous examples from around the world of both inter-and intra-project multiple discount rates. However, these appeared to be almost exclusively motivated by policy objectives rather than empirical evidence regarding underlying preferences. The management of discount rates to give policy-favoured projects

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[83] Under weak-sustainability further use of K_n up to the SMS must still be compensated for by reinvestment (savings) of the appropriate level of K_m proceeds from each project (Turner and Pearce, 1993).

[84] Under strong-sustainability an individual project must compensate K_n both in terms of K_m savings and by appropriate contributions to an offset physical compensation, shadow project fund. Such physical compensation must be actual rather than hypothetical (re rejecting the Hicks-Kaldor rule). A still stronger view (very strong sustainability) states that each project must have its own actual physical K_n compensation shadow project (see Turner and Pearce, 1993).

a spurious sheen of financial respectability is widespread and to be avoided.

The desirability of a single rate is therefore clear. The Pearce and Ulph (1995) results (central estimate r_s = 2.4%; range = 2-4%) are useful here but we have to recognise that probably the recreation benefits, and almost certainly the carbon sequestration benefits, of woodland would attract a lower than average rate of public pure time preference. Accordingly we have chosen a sensitivity analysis for r_s which includes one rate (1.5%) which falls below the Pearce and Ulph range[85] and another which is the centre of that range (3%). For comparative purposes we have also employed the Treasury's (6%) rate throughout, although we echo the sentiments of Pearce and Ulph that this seems "very difficult to justify".

6.6.2.1: Hyperbolic social discount rates

The standard discount function is most commonly expressed as the quotient shown in equation (6.11):

$$DF_t = \frac{1}{(1+r)^t} \qquad (6.11)$$

where:

DF_t	=	discount factor in year t
r	=	discount rate
t	=	time in years from the start of project (t=0,1,2,,,F)

While this is perfectly adequate for discrete time periods, discounting over continuous time is often performed using a mathematical equivalent of the quotient formula known as the negative exponential format as shown in equation[86] (6.12):

$$DF_t = e^{-\rho t} \qquad (6.12)$$

where

e	=	2.718, the base of natural logarithms
ρ	=	ln (1+r)

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[85] This also reflects the lower range estimates of Fankhauser (1993) and Arrow et al. (forthcoming).

[86] Price (1993) discusses the slight difference between the two definitions of the discount factor presented in equations (6.11) and (6.12).

The exponential nature of this relationship is taught as a first principle in most basic microeconomics courses and, if it is questioned at all, is usually justified with reference to the opportunity cost of capital link between the discount and interest rate, the latter being compounded at a positive exponential rate. However, basic textbooks in behavioural science teach, with equal certainty, that "research indicates that the discount functions usually take the form of a hyperbola", (Rachlin, 1991)[87] as shown in equation (6.13):

$$DF_t = \frac{1}{(1+rt)} \tag{6.13}$$

As indicated by this quotation, such a statement is based upon empirical findings. Indeed hyperbolic discount functions have been observed as the norm in the behaviour of adults (Mazur, 1987), children (Mischel and Baker, 1975; Mischel et al., 1989), non-human mammals (Menzel, 1971) and even birds (Rachlin and Green, 1972) suggesting that this may be a genetic trait common to all sentient beings.

Some behaviouralists have attempted to bridge the gap between their discipline and economics (see Rachlin, 1989) only to be met by a mixture of silence and dismissal[88]. However, such xenophobia may now be breaking down as economists begin to run experiments similar to those which behaviouralists have carried out for more than two decades.

In one such experiment, Cropper et al. (1992)[89] attempt to estimate r_s for future human lives. Some 3,200 US households were interviewed with respondents being presented with two hypothetical pollution control programmes only one of which the government could afford to fund. Programme X would save lives today and programme Y would save lives at a fixed point in time some years in the future. Although each respondent was presented with only one future scenario to weigh against the present-day programme, across the total sample five future alternatives were examined, fixed at 5, 10, 25, 50 and 100 years in the future. Answers to questions as to which programme should be funded allowed calculation of an implied exponential discount rate which, rather than remaining constant, declined from 16.8%

[87]See also the excellent introduction to this field given in Logue (1988).

[88]Loewenstein and Thaler (1989) conclude that "Many economists view the research on the psychology of decision making as a nuisance".

[89]Further results are reported in Cropper and Portney (1992).

for lives saved in year 5 (against lives saved now), to 11.2% in year 10, to 7.4% in year 25, to 4.8% in year 50 and, finally, to 3.8% in year 100. Henderson and Bateman (1995) examine the mathematical relationships underlying these results and find that the hyperbolic function given in equation (6.13) provides a near-perfect fit (R^2(adj) = 99.6%)[90].

Given the weight of evidence from behavioural and now economic research, why is the economic profession generally so dismissive of hyperbolic discount function. Two reasons appear predominant, the first being the link between discount and interest rates via the opportunity cost of capital. As interest rates compound exponentially so we would expect exponential discounting. This seems a sound argument but it is perhaps strongest for market and private discounting where the individual is constrained by lifespan to emphasise short run opportunity costs. We therefore do not attack the exponential nature of private discount rates. However, the link with short run interest is less strong for public discount rates and this brings us to the second, and we believe underlying Neoclassical objection to hyperbolic discounting: the problem of preference reversal.

Table 6.18 considers a particular project commencing in 1995 and yielding annual net benefits thereafter. Each cell in columns (1) to (4) gives the ratio of the present value of one pound received at the start of the specified year and one pound received at the end of that year. Columns (1) and (2) give this relationship as seen from the project start year using, respectively, exponential and hyperbolic discount functions (r = 6% throughout). In every case the discounted value of a pound received at the start of a year is more than that of a pound received at the end of that year (i.e. all ratio values are greater than one). However, using exponential discounting this year start/year end present value relationship is constant throughout the lifetime of the project, whereas for the hyperbolic discount function the relationship declines over time. This means that hyperbolic discount functions give relatively more weight to delayed net benefits than do exponential functions of the same discount rate[91]. This said, columns (1) and (2) do not seem to pose problems for project appraisal.

Such problems arise when we compare columns (1) and (2) with columns (3) and (4). These latter columns again show year start/year end discount ratios but now assessment is

[90]Optimum value of r is 21% (t value = 36.63). An intercept term, allowed for in our estimating equation, proved to be strongly insignificant from zero.

[91]The annual rate of present value decline is progressively slower under hyperbolic discounting whereas it remains constantly higher (at any give r) under exponential discounting.

made in 2015. As before the exponential ratios, in column (3), are constant across all years while the hyperbolic ratios, in column (4), decline with time. This means that, using exponential discounting (columns (1) and (3)) a choice between projects made in 1995 will remain optimal when reassessed in 2015. However, comparison of the hyperbolic ratios in columns (2) and (4) suggests that this may not always be so for now the same project year when assessed from different points in time has very different discount ratios.

Table 6.18: Start/end of year discount ratios from exponential and hyperbolic discount functions (r = 6% throughout)

Year	Project age in years (t)	Assessment in 1995		Assessment in 2015	
		Discount ratio (exponential discounting) (1)	Discount ratio (hyperbolic discounting) (2)	Discount ratio (exponential discounting) (3)	Discount ratio (hyperbolic discounting) (4)
1995	0	1.06	1.0600	n/a	n/a
2015	20	1.06	1.0288	1.06	1.0600
2025	30	1.06	1.0214	1.06	1.0340
2045	50	1.06	1.0137	1.06	1.0219
2065	70	1.06	1.0118	1.06	1.0152
2085	90	1.06	1.0096	1.06	1.0116

To illustrate this consider two projects. Project A yields a single net real benefit of £97 million in 2025 while project B yields a single real net benefit of £100 million in 2026. Table 6.19 details present values at our two assessment points, 1995 and 2015, calculated under both exponential and hyperbolic discounting (discount rate = 6% throughout).

Table 6.19 reveals some interesting differences between exponential and hyperbolic discounting. Because exponential discount factor curves decay much faster than their hyperbolic equivalent (at any given discount rate) the initial assessment in 1995 shows exponential curves favouring the more immediate if smaller benefits of project A while the enhanced future weighting of hyperbolic curves leads to a preference for the more delayed but larger benefits of project B. When the assessment point is changed to 2015, because of its constant annual discounting ratio, exponential curves still give the same result that project A is favoured. However, the steep initial decline of a hyperbolic curve, compared to its relatively shallow subsequent shape (see figure 6.10) means that now project A is preferred to project B, i.e. preferences have reversed.

Table 6.19: Hyperbolic discounting and preference reversal

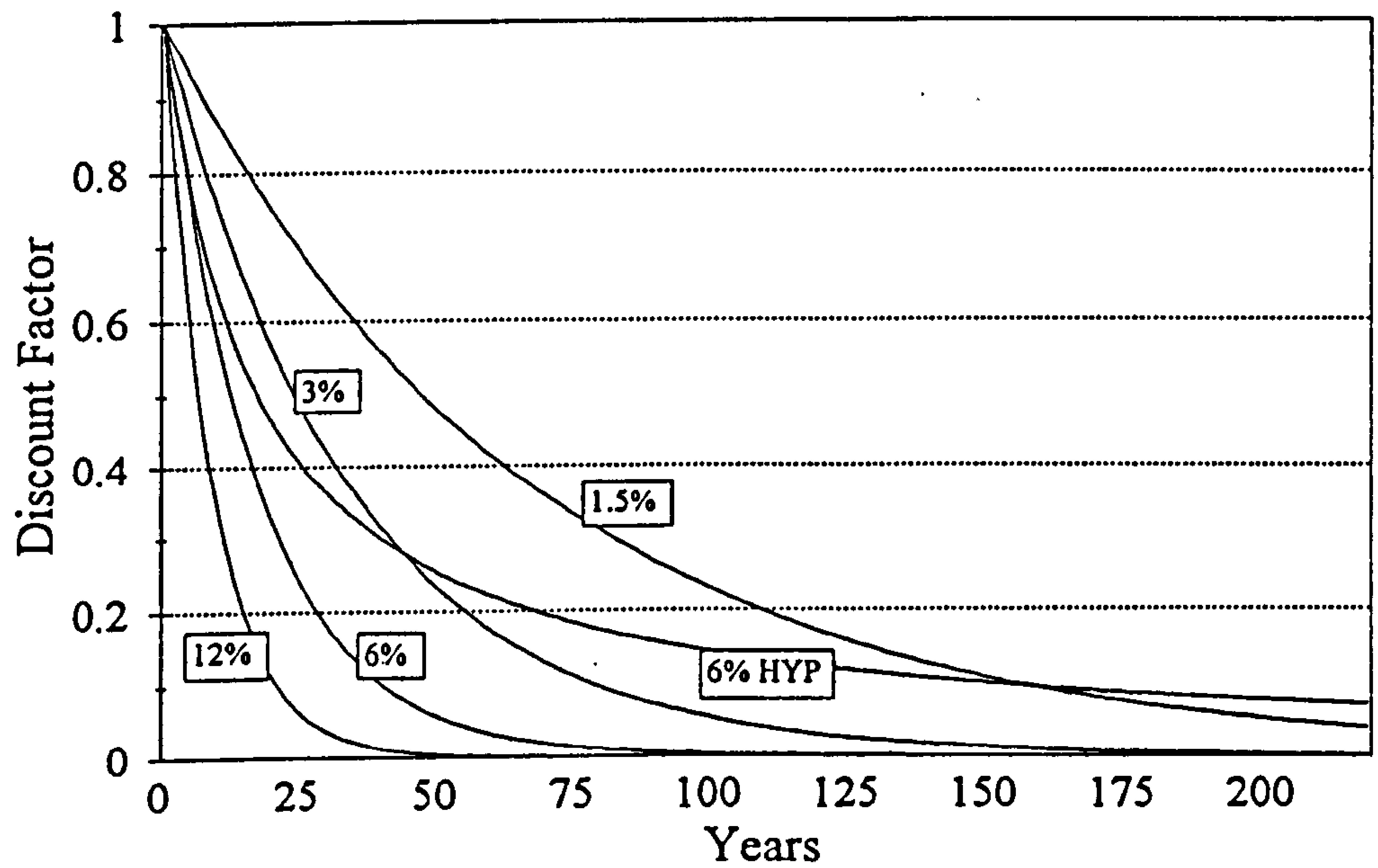
Project	Yield year	Undiscounted net benefit	Present value assessed in 1995 (r = 6%) Exponential discounting	Hyperbolic discounting
A B	2025 2026	£97M £100M	£16.9M £16.4M	£34.6M £35.0M
Decision			Prefer A	Prefer B
Project	**Yield year**	**Undiscounted net benefit**	**Present value assessed in 2015 (r = 6%) Exponential discounting**	**Hyperbolic discounting**
A B	2025 2026	£97M £100M	£54.2M £52.7M	£60.6M £60.2M
Decision			Prefer A	Prefer A

The apparent inconsistency of such preference reversals have been viewed with horror by those economists who have considered the behaviouralist literature. Such results have been presented under headings such as "Anomalies"; "Myopia and Inconsistency"; "Dynamic Inconsistency"; or "Myopic Discounting"[92]. Certainly the implications for project appraisal would appear to be major. However, the behaviouralist literature, which finds no problem with the notion that decisions might be time dependent and that people might change their mind as options come closer in time[93], notes that the possibility of subsequently changing ones mind often leads people to adopt 'commitment' strategies. Here individuals deliberately choose paths to lock out the possibilities for preference reversal for example by entering into long term repeated investment contracts (Logue, 1988; Rachlin, 1991).

[92]For a review see Henderson and Bateman (1993).

[93]An analogy (from Rachlin, 1991) is that of choosing between studying for an exam or going to the cinema. When both choices are distant a student may wish to study for the exam on a particular evening. However, when that evening arrives (with the exam still a few days hence) a human student (as opposed to the neoclassical model) may well crack, change his mind and see the film rather than studying. Whether or not such internal individual rationality should form the basis of public policy choices is an interesting question to which we do not have a ready answer.

Figure 6.10: Discount rate sensitivity analysis: Discount factor curves for chosen exponential and hyperbolic discount rates



Given that the adoption of strategies to avoid preference reversal implies that we wish to retain original assessment positions, the arguments surrounding the inconsistency of hyperbolic discounting seem to have more to do with defending standard economic assumptions rather than observed public preference behaviour. Consequently, in the face of evidence such as that of Cropper et al. (1992) and the vast array of empirical studies from the behavioural sciences, we feel that it is worthwhile pursuing the implications of adopting hyperbolic discount functions in our wider research.

6.6.3: DISCOUNT RATES: CONCLUSIONS

Given the major impact which alterations in the discount rate will have upon long-delayed forestry returns, we feel that our discussion highlights the need to adopt a sensitivity analysis approach to this issue. Considering exponential discounting first we feel that real social discount rates of 1.5% and 3% are well justified as a reasonable range here. Furthermore the Treasury's 6% rate is also included for comparative purposes. Turning to consider farmers real private discount rates, the 1.5% and 3% rates are useful for assessing decisions in the Welsh non-dairy agricultural sector[94]. Conversely rates of 6% and 12% roughly describe the reasonable limits which we may wish to apply to dairy farms in Wales.

We feel that their is a sufficiently strong case for assessing a hyperbolic social (if not private) discount function. We have chosen a hyperbolic rate of 6% as this gives a discount function curve which initially lies below the $1^1/_2\%$ exponential curve but is then cut from above by the latter to become the curve which most highly values long delayed net benefits (see figure 6.10)[95]. We feel that there is a strong theoretical and empirical case to suppose that this more accurately reflects public preferences for public goods in the long term.

6.7: THE PRIVATE VALUE OF TIMBER PRODUCTION

From the discussions of this chapter we can see that the private value of a productive plantation is determined by four broad categories of factors:

i. Plantation costs

As itemised in tables 6.9 (for conifers) and 6.13 (for broadleaves).

ii. Plantation timber benefits

These arise both through thinnings and maincrop felling. Crucial factors here are future real prices (which following our analyses, we assume to be constant) and yield class.

iii. Grants and subsidies

As discussed these will vary according to which schemes the farmer is permitted to register under; whether or not the farm is in a defined agriculturally disadvantaged area; and the prior use of the land. Tables 6.12 (for conifer) and 6.15 (for broadleaves) bring together cost, benefit and subsidy streams for a typical hectare of Welsh productive woodland.

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[94] We recognise that a number of these farms may not even be attaining rates of return of 1.5%. However, we feel many of these are not sustainable in the long term and will probably join the ongoing exodus from this sector. Our rates therefore apply to the remaining, sustainable non-dairy farms.

[95] The Treasury's 6% (exponential) rate was also a background factor here.

iv. Discount rate

We argue that this will be significantly higher for dairy as opposed to non-dairy Welsh farms.

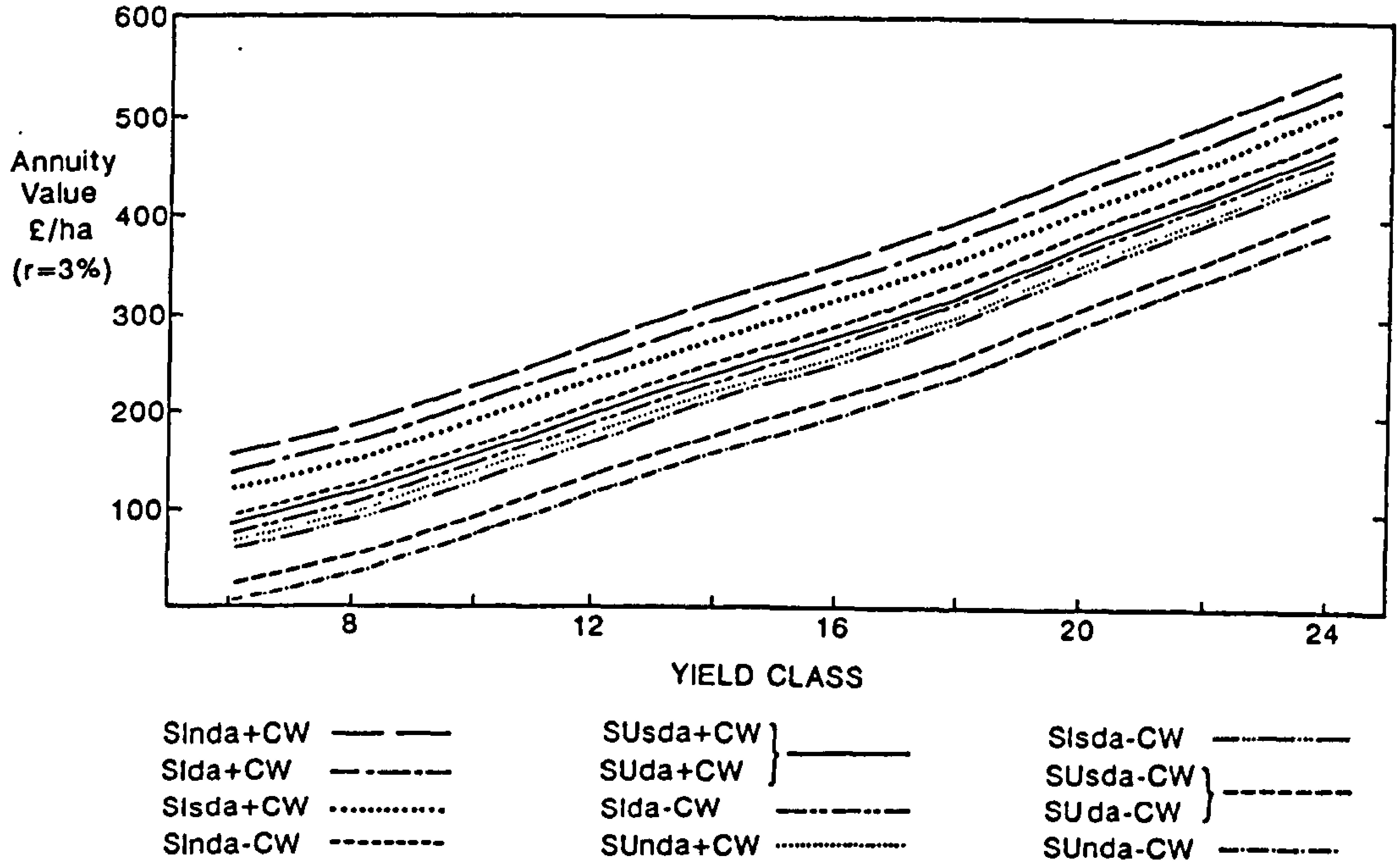
All these factors were brought together by inputting data from the FC yield models (Edwards and Christie, 1981) for Sitka spruce (YC6-24) and beech (YC4-10) to a series of MINITAB worksheets (MINITAB, 1994). This allowed easy manipulation of all assumptions (e.g. grant schemes, discount rates, optimal felling age[96], etc) to produce a full range of private values. Results from this exercise are reported in full in appendix 4.3[97]. As these are extensive we reproduce just one (exponential) discount rate scenario here. Figure 6.11 graphs annuity equivalents for a 3% discount rate for the full range of Sitka spruce YC's and all feasible grant scheme registrations (detailed in notes to the figure). Figure 6.12 repeats this analysis for beech.

For both Sitka spruce and beech we can see that, as expected, annual equivalent values rise with YC (just as they fall with discount rate; see appendix 4.3). As subsidy schemes are not linked to timber productivity the difference between scheme payments is constant within YC. Comparison between Sitka spruce and beech is interesting as it shows that, holding YC constant (i.e. YC 6, 8 or 10), returns from broadleaves are higher than for conifers. This is due to higher prices and subsidy levels for broadleaves and despite the shorter felling age of conifers. However, because conifers are capable of much higher YC than broadleaves and, more importantly, because such high yield plantations have much lower felling ages (thus avoiding the severe discounting visited upon long rotation broadleaves), they can provide much higher annual equivalents than broadleaves. Furthermore, as conifers typically perform better (in YC terms) than broadleaves on any given piece of ground, the financial attractions of conifers appear to outstrip those of broadleaves.

[96]Set as per tables 6.11 (for conifer) and 6.14 (for broadleaves).

[97]Appendix 4.3 reports NPV, perpetual sum NPV and annuity equivalents for each discount rate/YC/subsidy scheme permutation.

Figure 6.11: Farmers private values for Sitka spruce (annualised equivalents of a perpetual series of optimal rotations: £/ha; r=3%). Various yield classes and subsidy types.

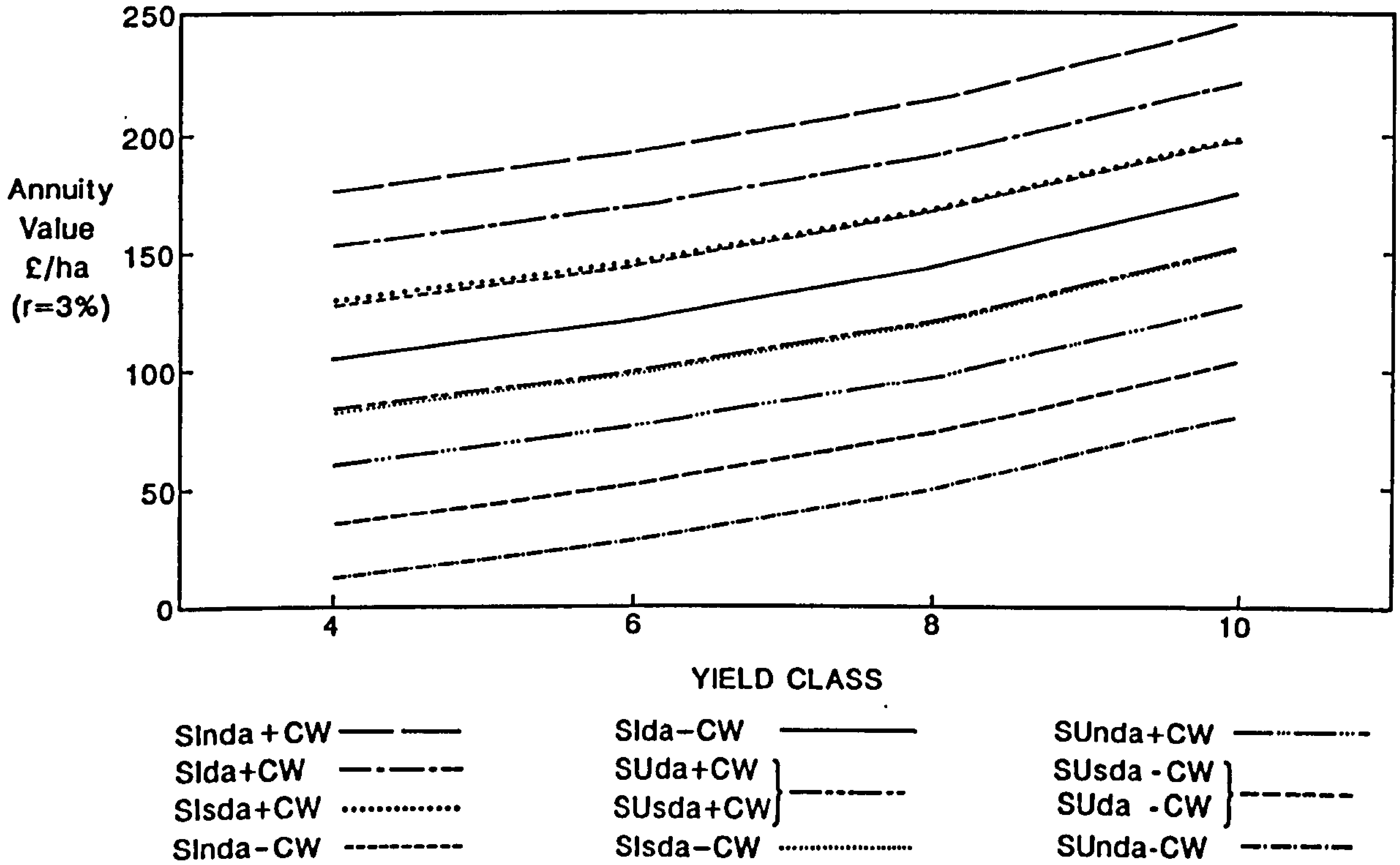


Note: Subsidy permutations are coded as follows:

SI = subsidy paid on land which was recently improved grassland/arable
SU = subsidy paid on land which was formerly unimproved grassland
nda = not a disadvantaged area
da = disadvantaged area
sda = specially disadvantaged area
-CW = community woodland supplement not paid
+CW= community woodland supplement paid
For rates of subsidy payments see section 6.5.

The impact of discounting is fully documented in appendix 4.3. However, an overview is given in table 6.20. Here annualised equivalents for highest output Sitka spruce (YC 24) and beech (YC 10) under one subsidy permutation are given for all discount rates (including some, such as the hyperbolic 6% rate, which are probably inappropriate for private farm decisionmaking, but are included for comparative purposes).

Figure 6.12: Farmers private values for beech (annualised equivalents of a perpetual series of optimal rotations: £/ha; r=3%). Various yield classes and subsidy types.



Note: Subsidy codes as per table 6.11.

Table 6.20: Farmers private values for YC 24 Sitka spruce and YC 10 beech (annualised equivalents of a perpetual series of optimal rotations: £/ha). Various discount rates. Subsidy option = SUnda-CW.

Discount rate	Farmers private value (annualised equivalent; £/ha)	
	Sitka spruce (YC 24)	Beech (YC 10)
1.5%	496.30	103.54
3%	388.46	80.68
6%	219.36	31.21
12%	19.45	9.59
Hyperbolic 6%	864.80	335.68

Notes: SUnda-CW = subsidy for previously unimproved grassland, not in a disadvantaged area and without community woodland supplement.

In subsequent chapters we examine how such forest values compare with returns to existing agriculture and forecast farmers likely conversion rates under present and possible future subsidy schemes.

6.8: THE SOCIAL VALUE OF TIMBER PRODUCTION

In moving from the private to the social value of timber production a number of issues need to be addressed. The basic plantation costs and timber (thinnings and maincrop) benefits can defensibly be used in an unaltered form. Unlike agricultural produce, timber prices are not intervened or otherwise controlled and, given that the UK domestic timber price is set by the competitive world market (see Appendix 4.1), we see no clear reason to embark on a price adjustment exercise. However, we do have to subtract all grants and subsidies as these are simply transfer payments. This gives us our baseline social value for timber net benefits which we detail for Sitka spruce and beech across all YC and discount rates in appendix 4.4.

As discussed in our opening chapter, the social value of a woodland is more than just the value of timber therein. In earlier work (Bateman, 1992) we identify and discuss a detailed set of environmental and non-environmental non-market costs and benefits which may arise from afforestation. Here we summarise that discussion by briefly considering the major non-market items which may need to be considered when moving from a private to a social assessment of woodland.

6.8.1: NON-ENVIRONMENTAL NON-MARKET SOCIAL COSTS AND BENEFITS

Here we discuss four major issues[98]; national security; economic security; import substitution; and employment.

i. National security

While this formed the impetus for the creation of the Forestry Commission just after WWI, and was an important spur to planting post-WWII, the prospect of the UK being blockaded from receiving timber supplies for any extended period seems rather unlikely. We therefore conclude that there is no significant national security benefits to be derived from the

[98]Further details in Bateman (1992).

expansion of a domestic supply capability.

ii. Economic security

While not of strategic importance, uninterrupted security of supply does bring avoided-cost benefits. In a study of this issue, Pearce (1991) states that "an evaluation of the chances of embargoes and other supply interruptions suggests that a small increment in prices of 0.2 to 0.8 per cent to reflect the shadow value of economic security would be justified". Accordingly timber benefits were increased by 0.5% in our social evaluation models[99].

iii. Import substitution

Although timber forms the UK's fourth largest import item (FICGB, 1992), the theory of comparative advantage shows that state-support of industries which do not enjoy such advantage is inefficient and does not constitute a social benefit.

iv. Employment

It has been argued that creating jobs in forestry is a good way to stem the ongoing trend of rural depopulation and combat the psychological and other economic costs of rural unemployment. However, numerous studies have suggested that forestry is a relatively expensive and therefore inefficient method of providing rural employment, particularly when compared to agriculture (H.M. Treasury, 1972; Laxton and Whitby, 1986; NAO, 1986; Johnson and Price, 1987; Evans, 1987). Forestry expansion could therefore be seen as creating shadow costs[100]. However, we do not feel this is likely in the case of Welsh farm-forestry and therefore feel that, in the absence of a specific study, though should be ignored with any net imbalance in private woodland versus agricultural net benefits indicating the farm level flows of social employment benefits.

In conclusion the only clearly valid non-environmental non-market social benefit we can isolate is a small benefit due to increased economic security of supply.

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[99]Note that this is an across-the-board single increase, not a compounding of an annual real price increase. Consequently the net effect is very small.

[100]This may be becoming less true as Forestry Commission employment has been falling, and productivity rising, since the late 1970's (Forestry Commission, 1979, 1989, 1994a; Thompson, 1990; FICGB, 1992).

6.8.2: ENVIRONMENTAL NON-MARKET SOCIAL COSTS AND BENEFITS

Woodlands create a myriad of social benefits and costs of which we discuss the following major issues[101]: recreation; carbon storage; non-user (bequest and existence) values; and acidification impacts.

i. Recreation

This is the major focus of our evaluation research as discussed in chapters 2-5. Because of the potentially significant problems of declining marginal utility[102], we have decided not to incorporate such benefits within the plantation value models presented in this chapter. Instead these models deal primarily with timber values to which recreation benefits are added in subsequent chapters[103].

ii. Carbon sequestration

As with recreation we have chosen to deal with carbon sequestration separately from our NPV models. This is not because of diminishing marginal utility, for (as explained in later chapters) the likely levels of sequestration will not have a significant impact upon the global CO_2 budget, but rather because of the complexities of this issue which we feel deserve particular separate attention.

iii. Non-user values

Travel cost and other revealed preference evaluation methods only address users direct-use value for a resource. To some extent the difference between this and the total economic value concept discussed in chapter 1 can be addressed via expressed preference methods such as contingent valuation. However, site surveys are still restricted to the values of users. Yet a considerable body of research exists to suggest that non-users may hold significant values for woodlands (Oosterhuis and Van der Linden, 1987; Willis and Benson, 1989; Kriström, 1990; Walsh et al., 1990; Bateman, Diamand and Langford, 1995; Bateman

[101]Further details in Bateman (1992).

[102]As the area of woodland expands we would expect the increase in recreation opportunities to result in an observable decline in per hectare recreation values. Given supply and demand conditions we would not expect this to be a problem for timber production.

[103]As discussed elsewhere this implicitly assumes that the monetary evaluations of woodland recreation are surpluses to the amenity value of the present agricultural landscape.

et al., 1996). These values arise because non-users see woodlands as a store of indirect use value (landscape amenity) bequest value (to others both now and in the future), and existence value (biodiversity, wildlife habitat, etc)[104].

These are quite clearly significant values. We have spent some time considering the landscape amenity problem (Bateman, 1994)[105] and our ongoing research is examining methods by which such values might be quantified[106]. The pure non-use issue is more problematic. A braver man than I might suggest that results from our non-user study at Wantage might provide estimates of this issue and indeed this was one of the prior objectives of that experiment. But as pointed out, the sample interviewed in that experiment almost uniformly viewed itself as potential users rather than actual non-users. Furthermore our other non-user CV surveys (Bateman et al., 1992, 1995; Bateman and Langford, forthcoming) have suggested that the technique is a rather crude tool here which may well be eliciting the 'warm-glow' type of response discussed in chapter 2. Certainly we feel that many of the major criticisms of the CV approach are most valid in the context of non-user surveys.

So we are left with having to acknowledge a possibly significant deficiency here. While we feel that our analysis is relatively sophisticated and useful in a policymaking context, it remains far from perfect. Our ongoing research into evaluation is examining this issue[107] but we cannot be certain of success here and only feel confident of predicting a relative improvement in methods over time.

iv. Acidification

In our detailed review (Bateman, 1992) we show that forests are both the victims and perpetrators of acidification damage[108]. While the Forestry Commission suggests that forests tend to act as a catalytic fixing medium for industrially emitted atmospheric acid (Innes, 1987), others suggest that this is only part of the story and that conifers in particular

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[104]Generally these values will be thought of as positive (i.e. woodlands providing benefits) but they may equally well be negative (e.g. single age Sitka spruce plantations reduce landscape amenity and biodiversity value; see Newton and Moss, 1981; Price, 1987, 1991; RSPB, 1987, 1988).

[105]See also review of Garrod and Willis (1992a,b,c) and Helliwell (1990) in appendix 1.

[106]Our ongoing research in this area examines the application of GIS viewshed and noiseshed routines to the hedonic pricing method. This research is sponsored by the ESRC and assisted by data from Professor Duncan MacLennan (CHRUS, University of Glasgow) and the Ordnance Survey.

[107]Particularly relevant here is our ongoing research regarding the demand for natural areas (sponsored by English Nature and the ESRC to whom we are indebted).

[108]Acidification of both waterways and soil is a recognised problem.

directly contribute to a lowering of pH levels (see Harriman and Morrison, 1982; Batterbee, 1984; Nisbet, 1990; and the particularly relevant papers in Edwards et al., 1990[109]). We take the position that whether or not forests actually generate the acids concerned, they are significantly linked to increased acidification of aquifers in non-buffered areas and therefore do generate costs. Our research in this area has not progressed beyond the level of a literature survey; however, this has shown that the acidification problem is eminently amenable to GIS analysis which we intend to proceed with shortly.

6.8.3: NON-MARKET SOCIAL COSTS AND BENEFITS: SUMMARY

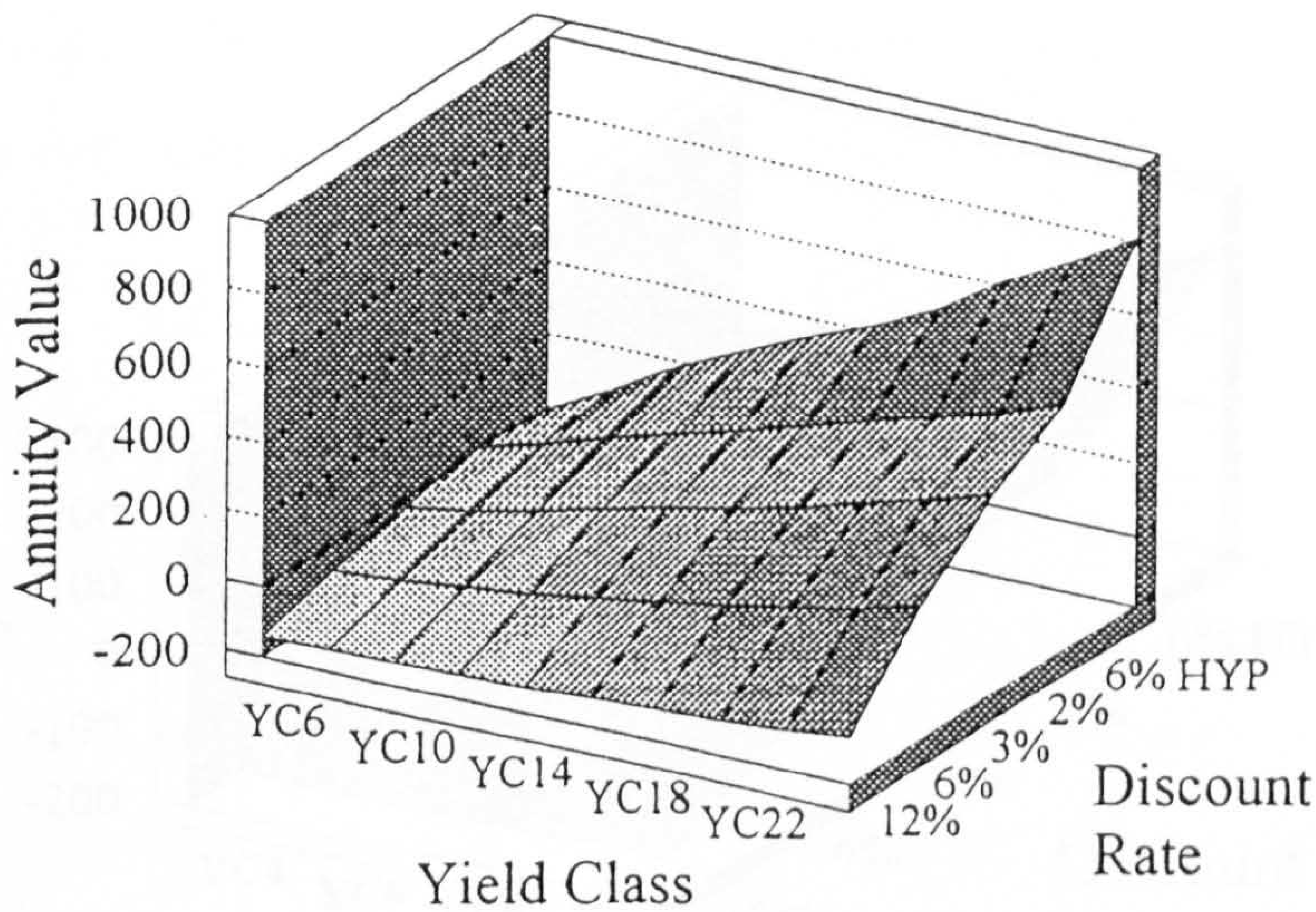
Those items which we feel to be of major significance (recreation and carbon sequestration) are dealt with outside our rotation model in other chapters. Of the remaining social costs and benefits, economic security arguments seem to justify a minor upward revision of social benefit values while most other issues appear insignificant with the exception of non-user (and possibly acidification) values. Both of these are the subject of ongoing research and we accept that this must remain a partial analysis until that work is complete. Nevertheless we would defend the present study as a significant improvement on existing CBA models and of considerable decisionmaking use.

6.8.4: ANNUAL EQUIVALENT SOCIAL VALUES

We can now calculate social net benefit values for our plantation models. These encompass all the above social benefit and costs categories with the exception of recreation and carbon sequestration (which are dealt with separately) and non-user and acidification values (which are the subject of ongoing research). In effect, after omitting those items dealt with elsewhere and those still under investigation, only the value of economic security of supply is sufficiently quantified to be added to our base social net benefits of timber. Full results from this exercise appear in tabular form in appendix 4.5. As there is no subsidy dimension to these calculations we can illustrate results across all YC and discount rates on a single graph as shown (in three and two dimensions) in figure 6.13, for conifer, and figure 6.14 for broadleaves.

[109] This collection of papers focusses exclusively upon acidification in Wales.

Figure 6.13: Social value for Sitka spruce (annualised equivalent of a perpetual series of optimal rotations). Various yield classes and discount rates.



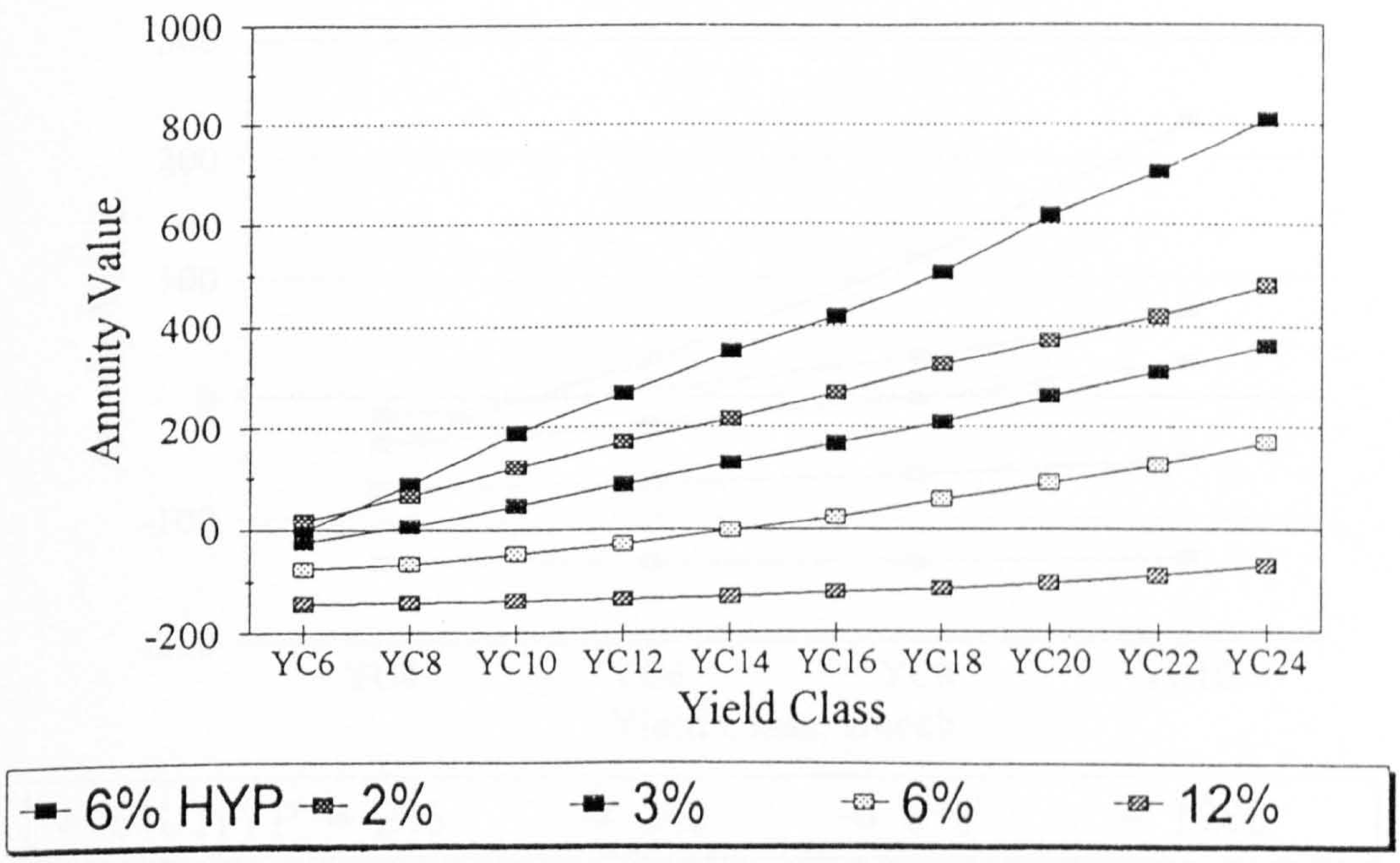
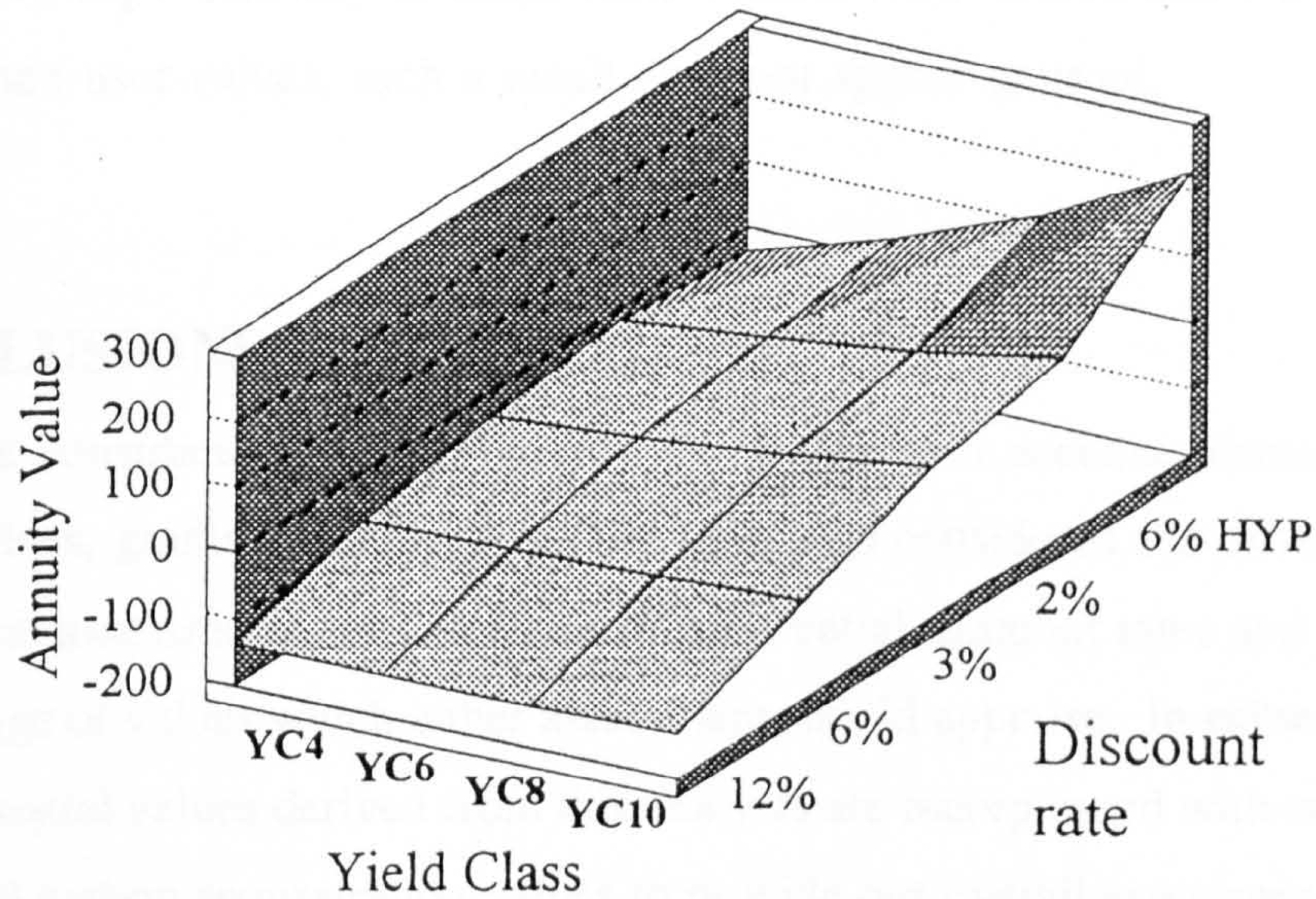
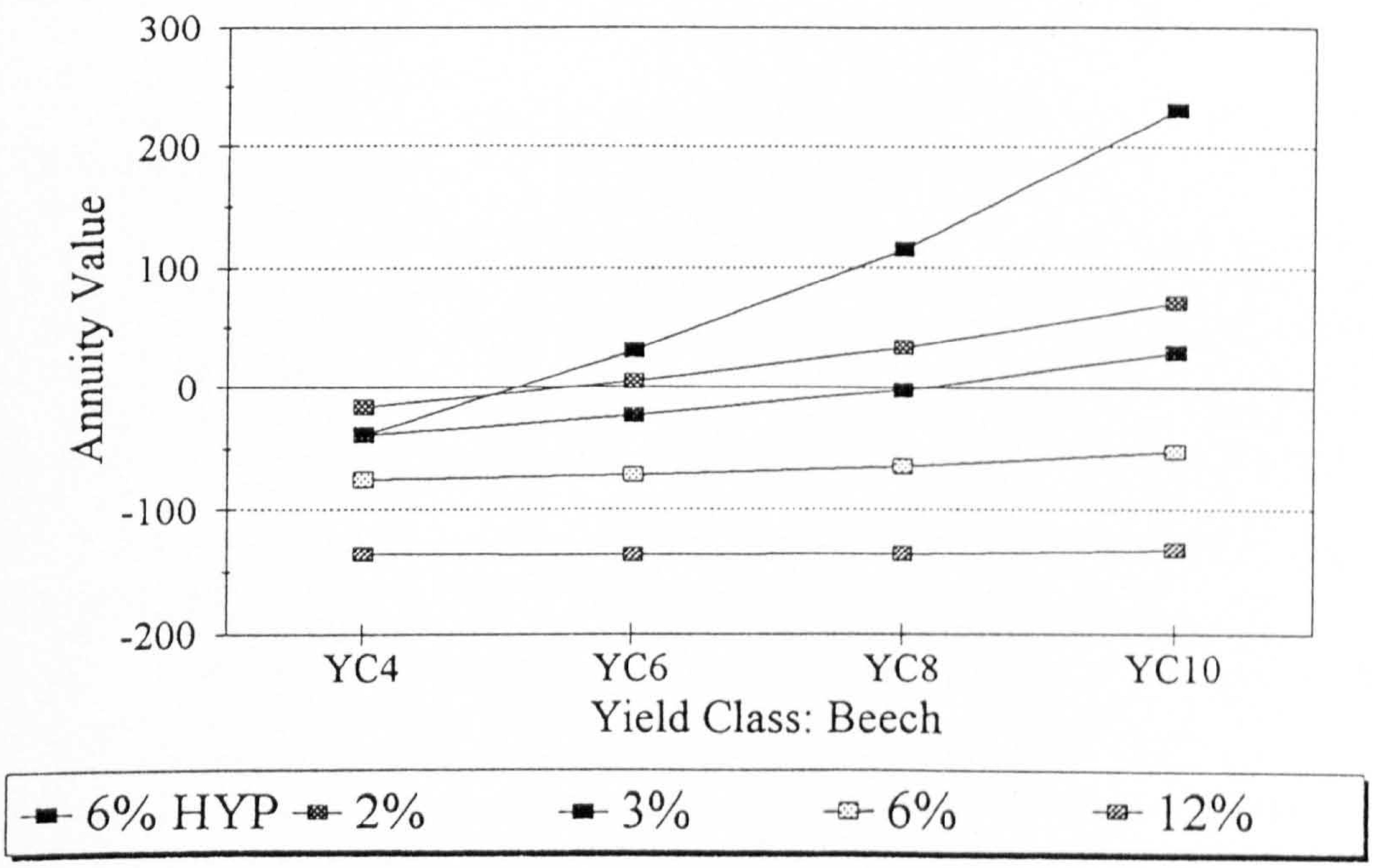


Figure 6.14: Social value for beech (annualised equivalent of a perpetual series of optimal rotations). Various yield classes and discount rates.





Comparison of figures 6.13 and 6.14 show relative relationships similar to those observed in the private sector evaluations. Again we see (on this restricted range of value types) conifers having the ability to outperform broadleaves. Given that we have excluded recreation and non-user values, such a result does not appear unusual.

6.9: CONCLUSIONS

We have constructed rotation models which take into account plantation costs and benefits, real prices, grants and subsidies. We have also considered the difference between private and social assessments both in terms of differential discount rates and with regard to the differing range of values which either assessment should appraise. In subsequent chapters the private and social values derived from this analysis are incorporated with our assessments of recreation and carbon sequestration values to provide our overall assessment of the values generated by farm-forestry. These values are then compared with those for existing agricultural activities so as to assess likely conversion rates under a variety of scenarios.

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Chapter 7: Modelling and Mapping Timber Yield and its Value

7.1 INTRODUCTION

In this chapter we present various models of the production of timber for the two species under consideration: Sitka spruce and beech. In Section 7.2 we present a brief review of previous studies. These have exclusively been based upon relatively small scale surveys of tree growth, furthermore, they have also generally been confined to comparatively small areas and often to one topographic region, e.g. upland areas. Our study differs from these previous models in that it uses a GIS to utilise large scale existing databases covering a very large and diverse study area; the whole of Wales. Section 7.3 presents details regarding the various datasets used in this study and discusses how these data were transformed for the purposes of subsequent regression analysis. Results from our models of Sitka spruce and beech growth rates are presented in Sections 7.4 and 7.5 respectively while Section 7.6 presents and analyses GIS created map images of predicted yield class. Finally Section 7.7 applies the findings of the previous chapter to produce monetised equivalents of these results.

7.2 LITERATURE REVIEW AND METHODOLOGICAL OVERVIEW

7.2.1 Literature Review

Clearly tree growth rates will depend upon a variety of species, environmental and silvicultural factors. Early work in this field relied on simple rules of thumb reliant upon relatively little supporting data (Busby, 1974) or analyses of single factors. Reviews across this literature provide a number of clues regarding the specification of a yield class (YC) model. An early focus of interest was the impact of elevation upon productivity (Malcolm, 1970; Mayhead, 1973; Blyth, 1974). Subsequent papers considered the various routes by which elevation affected YC including windiness (Grace, 1977), slope and aspect (Tranquillini, 1979). Other work examined the impact of factors such as soil type, soil moisture transport and droughtiness (Page, 1970; Blyth and Macleod, 1981; Jarvis and Mullins, 1987) and crop age (Kilpatrick and Savill, 1981). However, the estimation of statistical models across the full range of likely explanatory variables is a relatively recent innovation. Amongst such investigations we could find no examples concerning the productivity of beech and believe the model presented subsequently to be the first such investigation of this species. However, there has been more attention paid to the other species under analysis; Sitka spruce, which has been separately analysed both by Richard Worrell (then of the University of Edinburgh) and Douglas Macmillan (Macauley Land Use Research Institute, MLURI)[1].

While there had been a number of earlier considerations of factors affecting the growth of Sitka spruce (Malcolm, 1970; Malcolm and Studholme, 1972; Mayhead, 1973; Blyth, 1974; Busby, 1974; Gale and Anderson, 1984), the work of Worrell (1987a,b) and Worrell and Malcolm (1990a,b) is notable as being the first to adopt a multiple regression approach across a highly extensive range of explanatory variables. These were: elevation (including separate dummy variables for hilltop and valley bottom sites); windiness; temperature; aspect (measured as sine and cosine); and a full range of soil dummies. However, while this gives us vital pointers for our own modelling exercise, Worrell's results are not transferable to our Welsh case study. This is partly due to the upland Scottish location of Worrell's experiment but primarily as a result of the focus of his study. Worrell was mainly interested in detecting the influence of elevation upon YC in upland areas[2]. To this end he selected 18 principal sample sites[3], all of which had relatively steep slopes, and took measurements along a vertical transect at each site. By locating samples at sites ranging from 50 m to 600 m above sea level a very strong, central tendency relationship with elevation could be established. However, such a model is only applicable to similar, steeply sloping sites (strictly speaking, only the subset of those found within Scotland), and is not generalisable to the plethora of environmental conditions found in an area the size of Wales.

A similar, though less extreme, consideration prevents us applying the findings of Macmillan (1991). Here again the study is geographically confined, this time to lowland Scotland, although the 121 sites used are not selected to emphasise the influence of any particular explanatory variable and are therefore somewhat more generalisable within lowland areas. However, while this would, in many cases, be adequate, with respect to our study area the topographic variability of Wales means that a model based purely upon lowland data is insufficient for our needs. Nevertheless, the Macmillan paper is interesting for another reason

[1]I am grateful to both Richard and Douglas for extensive discussions of their work.
[2]An important question given that this is the location of much of the existing stock of Sitka spruce.
[3]The number of individual tree measurements is not reported.

in that it comprises multiple regression with a prior principal components analysis (PCA) of explanatory variables, reporting a final degree of explanation of R^2 = 36.8%[4].

A short note regarding model fit is justified here. As discussed in the previous chapter YC is the average annual growth rate of a plantation assessed over an optimal rotation. YC is therefore given in m^3 ha^{-1} yr^{-1}. However, YC values are rounded to the nearest even number so that while we have stands with YC 6 or 8 we do not have sites with YC 7. While this does not invalidate statistical analysis, as YC is the dependent variable, this approach to measurement does induce variance into the dataset and therefore makes high degrees of explanation difficult to attain. As such the absolute value of fit statistics such as R^2 should be treated with some caution and instead we should consider relative degrees of fit compared to those attained in other studies.

7.2.2: Overview of modelling approach

These prior studies provide very useful indications regarding the likely explanatory variables which should be considered in our analysis. The differences in modelling approach are also of interest and we consequently decided to investigate both a PCA and standard multiple regression methodology. However, in other respects the methods of Worrell and Macmillan were not appropriate to the specific types of question asked in our research. Our central aim is to identify areas over the entire surface of Wales which might be suitable for conversion out of agriculture and into forestry. This necessitated the development of a methodology which was capable of producing estimates for both upland and lowland areas and which had the capability of extrapolating such findings across the entire surface area of the country. To this end we adopt a GIS/Sub-Compartment Database (SCDB) approach to modelling[5]. This takes our base YC data from the Forestry Commission (FC) SCDB (described in detail subsequently) which holds information on each discrete stand (sub-compartment) in the FC's estate[6]. As this covers both upland and lowland sites, results from such a model is more generalisable than those described previously. Use of the SCDB has

[4]Although not specified this appears to be an unadjusted R^2 statistic.

[5]While there has been recent interest in the application of GIS to agricultural modelling (Moxey, 1996) this is the first GIS based application to timber production utilising multiple data sources and variables. An alternative approach using Landsat Thematic Mapper data is presented by Gemmell (1995).

[6]We are greatly obliged to Adrian Whiteman, Chris Quine and the Forestry Commission for use of the SCDB.

the added bonus of massively increasing our sample size relative to previous studies. However, rather than relate YC to the environmental variables reported in the SCDB, we extract these from a separate database, LandIS[7] (described subsequently), which has complete national coverage (unlike the SCDB which only has data for forest areas). Our regression results can then be readily extrapolated to all other areas of Wales, including those not presently under forestry. The one disadvantage of such an approach is that, unlike the previous studies, here the data is not collected directly by the researcher but by many others, often over an extended period. While this can be viewed as not entirely negative, subsequent modelling indicated that allowances had to be taken for variance induced by such an approach to measurement.

7.3 DATA AND DATA MANIPULATION

This research relies upon a diversity of data sources. Two already mentioned are the Forestry Commission's Sub-Compartment Database (SCDB) and the Soil Survey and Land Research Centre's LandIS database. In addition to this, further environmental and topographic data was obtained from a variety of sources. In this section we describe these data and how they were manipulated prior to consideration within the subsequent statistical investigation of tree growth. It is important to remember that, while the SCDB holds detailed data regarding individual plantation sites, it does not extend to the majority of Wales which is unplanted. Therefore the environmental variables given in the SCDB are, for our purposes, unsuitable predictions of YC as complete land surface coverages for these variables are not available and therefore cannot be used for extrapolation of predictions to presently unplanted areas. The complete coverages of variables held in LandIS and the other data described subsequently are therefore needed to allow for this extrapolation of regression results.

7.3.1: SCDB DATA

The SCDB is the Commission's central forest inventory detailing observations for all stands in the Estate[8]. As such it provides an invaluable source of high quality data. Some of this concerns internal administration and was not of interest to our investigation and so the

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[7]We are greatly obliged to Arthur Thomasson, Ian Bradley and the Soil Survey and Land Research Centre (Cranfield) for use of Land IS.

[8]The FC were, as always, most willing to allow access to their data, for which we are most grateful.

final list of variables extracted for this study was as detailed in Table 7.1. This also shows how certain of this data was manipulated to produce further (often dummy) variables. In doing this, one-way analyses of variance on the dependent variable (YC) were used to identify likely significant divisions in the data.

The SCDB also contains a variety of sub-compartment specific environmental variables such as soil type, altitude, terrain type and windblow hazard class. Normally these would be ideal for modelling purposes. However, as the FC only holds such data for those grid squares in which it has plantations, and since these are not (with the exception of altitude) variables for which uninterrupted national coverages exist, findings based upon such data would not form a suitable basis for extrapolation to other, currently unforested areas. This is somewhat unfortunate as this site specific data is almost certainly more accurate than that obtainable from more general databases such as LandIS. This means that the regression models produced using LandIS will not fit the YC data as well as those using the site factor information given in the SCDB. However, for the purposes of this research, the advantage of being able to extrapolate out across the entire surface of Wales and consider currently unplanted areas easily outweighs such costs (which we subsequently argue, on the basis of our results, are likely to be small).

In all records for some 6082 Sitka spruce and 766 beech sub-compartments were used in our regression analysis[9]. This represents a very significant increase over sample sizes used previously in the literature. These observations were distributed throughout upland and lowland Wales providing a good basis for extrapolation of results to other, presently unforested areas.

[9]Appendix 5 details descriptive statistics for variables used in our best fitting Sitka spruce and beech YC models as detailed subsequently. Chapter 10 illustrates locations of Sitka spruce sub-compartments superimposed upon an elevation map (figure 10.9).

Table 7.1: Variables obtained from the SCDB (except where shown otherwise). Ordered as per the database.

Variable name	Values	Notes and recodings (in italics)
Grid reference	Easting Northing	100 m resolution OS grid references
Land use/crop type	PHF = plantation high forest PWB = uncleared windblown area PRP = research plantation	*uncleared* = 1 if PWB = 0 otherwise *research* = 1 if PRP = 0 otherwise
Storey	1 = single storey 2 = lower storey 3 = upper storey	*single* = 1 if single storey = 0 otherwise
Species	SS = Sitka spruce BE = beech	Used to identify target species
Planting year	Discrete variable	*plantyr*: year in which stand was planted
Survey year	Discrete variable	*survyr*: year in which stand was surveyed[1]
Yield class	Even number	*YC*: tree growth rate: average m^3/ha/year over an optimal rotation - the dependent variable
Productive forest area	Ha	*Area*: stocked area of the sub-compartment
Unproductive forest area	Ha	*Unprod*: the area within the sub-compartment which has a permanent affect upon the crop, e.g. rocky outcrops, etc.
Rotation	1 = 1st rotation on formerly non-forest land 2,3 etc. = 2nd, 3rd rotation, etc. 9 = historical woodland sites S = ancient, semi-natural woodland	*1st Rot* = 1 for 1st rotation; = 0 otherwise *2nd Rot* = 1 for 2nd rotation; = 0 otherwise (Note for BE this includes some subsequent rotations.) *Historic* = 1 if historic site; = 0 otherwise *Semi-nat* = 1 if ancient/semi-natural woodland = 0 otherwise
Mixture	P = single species crop M = mixed species crop	*Mixed* = 1 if mixed crop; = 0 otherwise
Legal status	P = purchased by FC L = leased E = extra land, managed by FC outside legal boundary	*Purchased* = 1 if purchased; = 0 otherwise *Leased* = 1 if leased; = 0 otherwise *Extra* = 1 if extra; = 0 otherwise
Landscape	1 = National Park 2 = AONB/National Scenic Area 3 = ESA (where not included in 1 or 2 above)	*NatPark* = 1 if National Park; = 0 otherwise *AONB/NSA* = 1 if AONB/National Scenic Area = 0 otherwise *OthESA* = 1 if ESA area not included in above = 0 otherwise
Forest Park	1 = Forest Park	*FPark* = 1 if forest park; = 0 otherwise
Conservation	1 = SSSI (Site of Special Scientific Interest) 2 = NNR (National Nature Reserve) 3 = Non-FC Nature Reserve	*SSSI* = 1 if SSSI, = 0 otherwise *NNR* = 1 if NNR, = 0 otherwise *NonFCNR* = 1 if Non FC nature reserve; = 0 otherwise
FC Conservation	1 = Forest Nature Reserve 2 = Other FC conservation	*FCNR* = 1 if Forest Nature Reserve; = 0 otherwise *FCcons* = 1 if other FC; = 0 otherwise
Ancient monument/ woodland	S = scheduled ancient monument U = unscheduled ancient monument W = ancient woodland	*Ancient* = 1 if S, U or W, = 0 otherwise *Monument* = 1 if S or U, = 0 otherwise
		Further recodes from above: *NpAonbSa* = 1 if any of Nat Park or AONB/NSA = 0 otherwise *Cons* = 1 if any of NNR, NonFCNR, FCNR, FCons = 0 otherwise *Reserve* = 1 if any of Cons, AONB/NSA, OthESA = 0 otherwise *Park* = 1 if any of Nat Park, F Park, SSSI = 0 otherwise

Note: 1. Supplied by Chris Quine at the FC Northern Research Station, Roslin, to whom we are very grateful.

7.3.2: LANDIS DATA

7.3.2.1: Background

The first systematic attempt to analyze and record British soil information was the "county series" of maps initiated by the Board of Agriculture in the late 18th and early 19th centuries. Until comparatively recently this remained the standard and unsurpassed source of soil data. During the 1940s the Soil Survey of England and Wales (SSEW) began a detailed mapping initiative. However, by the late 1970s, only one fifth of the country had been covered. In 1979 the SSEW, which in the late 1980's become the Soil Survey and Land Research Centre (SSLRC), commenced a five-year project to produce a soil map of the whole of England and Wales and to describe soil distribution and related land quality in appropriate detail.

The data collected in this exercise was digitised, spatially referenced, and subsequently expanded to include climate and other environmental information (Bradley and Knox, 1995). The resulting land information system (LandIS) database was initially commissioned by the Ministry of Agriculture, Fisheries and Food, with the stated aim of "providing a systematic inventory capable of being used or interpreted for a wide range of purposes including agricultural advisory work, but also for the many facets of *land use planning and national resource use*" (Rudeforth *et al.*, 1984; emphasis added). However, although the maps and accompanying bulletins were completed in 1984 there has never been any major attempt since then to incorporate them into policy making. The present research therefore represents one of the first attempts to use LandIS for its originally intended purpose: national land use planning[10].

7.3.2.1: The data

Definitions, derivations and accuracy of the data extracted from LandIS are presented in Appendix 5.1. These are summarised in Table 7.2. Further details of LandIS and the data therein are given in Jones and Thomasson (1985) with discussion of Welsh conditions given by Rudeforth *et al.*, (1984). LandIS data is supplied at a 5 km resolution.

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[10]Agreement to use the data was obtained from Arthur Thomasson in 1987. However, at the time the SSEW was undergoing the trauma of being privatised, 'downsizing', and becoming part of what is now Cranfield University. We are grateful to Ian Bradley and R.J.A. Jones of the SSLRC for subsequently honouring this commitment and to the School of Environmental Sciences/UEA for funding the entailed data transfer costs.

Table 7.2: Variables obtained from LandIS

Variable name	Label	Definition
Accumulated temperature	*Acctemp*	Average annual accumulated temperature (in °C) above 0°C
Accumulated rainfall	*Rainfall*	Average annual accumulated rainfall (in mm)
Available water	*Avwatgra*	Amount of soil water available for a grass crop after allowing for gravity induced drainage
	Avwatcer	As per Avwatgra but adjusted for a cereal crop
	Avwatpot	As per Avwatgra but adjusted for potatoes
	Avwatsb	As per Avwatgra but adjusted for sugarbeet
Moisture deficit	*Mdefgra*	The difference between rainfall and the potential evapotranspiration of a grass crop
	Mdefcer	As per Mdefgra but adjusted for a cereal crop
	Mdefsbpt	As per Mdefgra but adjusted for a sugarbeet/potatoes crop
Field capacity	*Fcapdays*	Average annual number of days where the soil experiences a zero moisture deficit
Return to field capacity	*Retmed*	Median measure from a distribution of the number of days between the date on which a soil returns to field capacity and 31st December of that year
	Retwet	The upper quartile of the above distribution (measure of return to field capacity in wet years)
	Retdry	The lower quartile of the above distribution (measure of return to field capacity in dry years)
End of field capacity	*Endmed*	Median measure from a distribution of the number of days between the 31st December and the subsequent date on which field capacity ends
	Endwet	The upper quartile of the above distribution (measure of the end of field capacity in wet years)
	Enddry	The lower quartile of the above distribution (measure of the end of field capacity in dry years)
Workability	*Workabil*	A categorical scale indicating the suitability of the land for heavy machinery work in spring and autumn
Spring machinery working days	*SprMWD*	The average number of days between 1st January and 30th April where land can be worked by machinery without soil damage
Autumn machinery working days	*AutMWD*	The average number of days between 1st September and 31st December when land can be worked by machinery without soil damage
Soil type	See Table 7.3	SSLRC soil type classification code

An immediate problem with the LandIS data was the plethora of differing soil codes. These are taken from SSEW (1983) which lists many hundreds of separate soil types, a large number of which were present in our Welsh dataset. This level of detail far exceeds that used in previous YC studies such as Worrell (1987b) who uses seven soil type dummies derived from information given in the SCDB which in turn relies on the standard FC classification of soils. The large number of soil codes given in LandIS are a problem both because of their implication for degrees of freedom in our subsequent regression analysis and because any such results would be of little practical use to the forester familiar with an alternative and simpler system. Furthermore, consultations with an expert in the field of soil science and forestry suggested that, for our purposes, many of the SSLRC soil codes could be merged with no effective loss of information and a substantial increase in clarity[11]. Details of the final categorisation are given in Table 7.3.

Table 7.3: Soil type codes

Soil type[1]	Variable label	Subsumed SSLRC soil codes [2]
Lowland lithomorphic	*soil 1*	361
Brown earths	*soil 2*	514, 541, 551, 561, 571, 572
Podzols	*soil 3*	572
Surface water gley	*soil 4*	611, 631
Stagnogley (perched watertable)	*soil 5*	651, 654, 711, 712, 713, 721
Ground water gley	*soil 6*	813
Peats	*soil 7*	1011, 1013
Upland lithomorphic	*soil 8*	311
Urban	*n/a*	n/a

1. In our analysis of farm outputs (Chapter 9) we additionally assume that the dominant soil type on a farm is an adequate representation of all soils on that farm.
2. Here we have only listed categorisations down to the subgroup level (as defined in Avery, 1980). LandIS further subdivides these into numerous soil associations as detailed in SSEW (1983).

Subsequent statistical analysis suggested that, if anything, merging of soil codes could have been taken even further and some combinations of the variables given in Table 7.3 are considered later.

7.3.3: OTHER DATA

7.3.3.1: Topex and wind hazard[12]

Topex is a measure of the topographical shelter of a site. It is usually determined as

[11] Dr Bill Corbett of the School of Environmental Sciences, UEA, and formerly of the SSEW, kindly advised in the merging of soil codes to produce a simple eight-category system which groups together similar soils.

[12] 1 km referenced data on topex and wind hazard were kindly supplied by Chris Quine at the Forestry Commission's Northern Research Station, Roslin, to whom we are very grateful.

the sum of the angle of inclination for the eight major compass points of a site (Hart, 1991). Here then a low angle sum (low topex value) represents a high degree of exposure. The resultant variable was labelled *Topex 1 km.*

Blakey-Smith *et al.* (1994) define wind hazard on the basis of four factors[13]:

i. wind zone - delimited on a GB map;
ii. elevation - high values increasing wind hazard;
iii. topex - as defined above;
iv. soil type - those which relatively speaking promote growth (brown earths, podzols, etc.) being low wind hazard while those which restrict growth (gleys, peats, etc.) are higher wind hazard.

The resultant continuous variable (*Wind 1 km²*) is inversely linked with tree productivity and growth rates.

7.3.3.1: Elevation and associated variables

The work of Worrell and Malcolm (1990a) shows that elevation and its associated characteristics are key predictors of YC. However, such a variable is not included in the LandIS database and the SCDB only gives heights for existing plantation sites. Clearly for extrapolation purposes this is inadequate and so an alternative source of data was required. This was provided in the form of a GIS digital elevation model (DEM)[14]. The DEM is a GIS-based digital image of the topography of Wales. This was created from three principal data sources:

i. The Bartholomew 1:250,000 database for the UK. This gives 50 m contours up to 1000 m after which 100 m intervals are reported.
ii. Spot heights from Bartholomew's paper maps. These were particularly useful for assessing the predictive accuracy of the DEM and for addressing the problems

[13]Blakey-Smith *et al.* (1994) also discuss a funnelling variable which tends to have higher values in valley bottoms.
[14]The DEM was custom-created for this research by Julii Brainard and Andrew Lovett of the School of Environmental Sciences, UEA, to whom I am most grateful.

associated with identifying mountain tops.

iii. Spot heights of plantations from the SCDB. This provided additional information used in the interpolation of heights between contours.

After exhaustive accuracy testing of the resulting elevation variable (*Wselvgr2*), the authors of the DEM also used it to provide two further GIS surface variables: slope angle (*Dsl2*) and aspect angle (*Wsaspgr2*). Data on all these variables was supplied at a 500 m resolution.

7.3.4: Creating GIS surfaces for explanatory variables

Prior to the regression analysis two fundamental issues had to be addressed regarding the definition of a common extent and common resolution for the environmental variables. While the geo-referenced data obtained from the LandIS and non-SCDB sources detailed above were converted into GIS surfaces, inspection of these showed that the various data obtained differed both in its geographical extent and spatial resolution.

Data were supplied at a wide array of resolutions ranging from the (nominal) 100 m accuracy of the SCDB to the 5 km tiles of the LandIS variables. While the interpolation facilities available within the GIS made conversion to a common scale relatively straightforward,[15] choice of that scale was a matter for some deliberation. While standardisation upon the smallest unit (100 m) is given the interpolation capabilities of a GIS, perfectly feasible, it did not seem a sensible choice. The 100 m reference used in the SCDB is, the FC admit, spuriously precise. Furthermore, use of a larger scale would, in the case of say the DEM entail an averaging out of predictions which was likely to avoid problems associated with single point estimates. However, aggregation up to the 5 km scale of the coarsest data was felt to be likely to result in a loss of valid and interesting detail. Consequently a 1 km grid was settled upon and all data were interpolated to this resolution.

The spatial extent of Wales was defined by rasterising on to a 1 km grid the Bartholomew's vector data for the coast and border with England. This resulted in a GIS

[15]This is somewhat misleading. In reality careful interpolation is a highly time consuming exercise involving the iterative reassessment of a range of interpolation decay weights with actual versus predicted verification. Whilst advances in processor speed have considerably improved the time which such analyses take, they are still somewhat arduous to undertake. This issue is addressed at length in Bateman, Lovett and Brainard (forthcoming).

surface consisting of 20,563 land cells which was used as a mask file to extract 1 km values for each of the variables in the LandIS and non-SCDB datasets described above. However, in undertaking this exercise it was found that, with the exception of the custom written DEM and associated variables, virtually all variables were missing at least some observations. Given our principal aim of extrapolating regression results across the whole of Wales, this situation had to be rectified.

In some cases the problem of missing data was relatively minor. With respect to the topex and wind hazard data, which was supplied in a 1 km rasterised form, just 103 of the required 20,563 cells were missing, all of these being located at the tips of various peninsula. Here interpolation from surrounding cells provided a ready solution to this problem.[16]

The missing data problem was more serious in the LandIS database both because more data tiles were missing and because of their larger, 5 km, resolution. Using the OS grid, Wales extends to some 942 of these tiles[17]. Only three of the variables described in Table 7.2 had data for all of these tiles. Table 7.4 lists omissions from this database.

Table 7.4: Omissions from the LandIS database

Variable label[1]	No. of 5 km land tiles[2] supplied	% of all Welsh 5 km land tiles
Acctemp. Growseas, Grazseas	942	100.0
Rainfall, Retmed, Retwet, Retdry, Endmed, Endwet, Enddry, Fcapdays	898	95.3
Mdefgra, Mdefcer,	858	91.1
Avwatgra, Avwatcer, Avwatpot, Avwatsb	812	86.2
Workabil, SprMWD, AutMWD, Soils	780	82.8

1. From Table 7.2.
2. This includes any 5 km OS grid square containing any Welsh land (some may be mainly in England or in the sea).

[16]This and subsequent interpolation operations were conducted by Andrew Lovett, to whom I am very grateful.

[17]Note that coastal and border tiles will not be fully filled. This accounts for the implicit difference in the extent of this coverage as opposed to the 1 km mask.

As before the majority of omissions were clustered around the Welsh coast. However, to allow our extrapolation analysis to proceed, such empty squares had to be filled. Inspection of nearby cells for which data was available showed strong spatial trends in all variables with the exception of soil type. Consequently empty cells for all non-soil variables were filled using interpolation techniques. These were clearly inappropriate for soil type which tended to change abruptly and was consequently not interpretable from other data points.

Interrogation of the Bartholomew's digital database identified 19 of the 162 5-km grid squares missing soil values as being urban areas in which soil surveys had not been undertaken. The remaining missing values were filled by consulting the SSEW 1:250,000 Soils of Wales paper map.

All the LandIS data was the interpolated on to a 1 km grid and our coast/border outline used to delete squares which fell outside this extent.

With all data now at a common resolution and extent we now had the necessary complete surfaces of potential predictor variables for use in our regression model and from which extrapolation across all areas, whether currently planted or not, would be possible.

A final task concerned the extraction of values for all environmental variables for each YC observation in the SCDB. This was achieved via a GIS macro command[18].

7.3.5: PRINCIPAL COMPONENTS ANALYSIS

As discussed in our literature review, two approaches have been adopted for the statistical modelling of YC data. While Worrell (1987a,b) and Worrell and Malcolm (1990a,b) use conventional regression analysis, Macmillan (1991) first subjects explanatory variables to a principal components analysis (PCA) before entering the resultant factors within a regression analysis. It was decided that a comparison of these two approaches would be of interest and so our data was made the subject of a PCA.

Discussion of the PCA approach is given in Johnston (1978), Norusis (1985) and Dunteman (1994). PCA is in fact a special case of factor analysis (Lewis-Beck, 1994) and we shall use the terms 'factor' and 'component' interchangeably in the following discussions.

In essence PCA attempts to identify patterns of covariance so that trends within a

[18]This was custom written by Andrew Lovett, at UEA, to whom I am most grateful.

comparatively large number of variables are summarised by a smaller number of factors, i.e. it seeks to identify patterns of common variance. For example, in our literature review, we noted that the negative relation between YC and altitude was actually the product of a range of interrelated variables including elevation, slope, aspect, temperature, etc. A general 'height' factor which reflected these interrelations might therefore prove a strong predictor of tree growth. Norusis (1985) identifies four steps conducted in PCA:

1. A correlation matrix is prepared so that variables which do not appear to be related to others within the dataset can be identified (suppression-type problems can also be identified at this stage). The appropriateness of PCA can also be assessed at this point.

2. The number of factors necessary to adequately represent the dataset is identified. Clearly unless this is substantially less than the number of variables then the exercise is of little value.

3. The factors may be transformed (rotated) to make them more interpretable.

4. Factor scores are computed to indicate how individual observations perform on each factor. These may then be used as predictors within a regression model.

However, before we could start our PCA study we were concerned to first consider whether a single analysis might be appropriate for both Sitka spruce and beech sites or not. By dividing our data into two sets according to whether sites were planted with Sitka spruce or beech it was noted that the former generally faced more adverse environmental conditions to the latter. Table 7.5 details summary statistics for certain environmental variables divided according to site species[19].

[19]Descriptive statistics for the full range of environmental variables as used in our best fitting YC models for Sitka spruce and beech are detailed in Appendix 5.

Table 7.5: Description of environmental variables for forestry sub-compartments by species (SS = Sitka spruce; BE = beech)

Variable	Species	Mean	Median	St. dev.	Coef. of Variation
Wselvgr2	SS BE	323.70 196.83	333 183	102.72 99.90	31.7 50.8
Wind1km2	SS BE	14.890 12.009	14.96 11.89	2.36 2.25	15.9 18.8
Acctemp	SS BE	1401.2 1591.8	1385.0 1600.0	243.70 240.90	17.4 15.1
Rainfall	SS BE	1713.6 1386.5	1705.0 1284.0	433.80 423.50	25.3 30.5
Fcapdays	SS BE	313.39 267.29	322.0 258.0	48.27 56.19	15.4 21.0
MdefGra	SS BE	25.30 57.00	20.0 53.0	25.54 38.20	100.9 67.0
AutMWD	SS BE	2.122 16.623	0.0 0.0	9.66 24.23	455.2 145.8

Table 7.5 indicates that, on average, Sitka spruce sites are at higher elevation, colder, wetter and less workable than their beech counterparts. This is not surprising as we would expect broadleaf plantations to be generally confined to relatively lowland areas while hardy species such as Sitka spruce have been planted over a wide variety of sites. This substantial difference in site characteristics suggested that separate rather than common PCA investigations of explanatory variables should be conducted.

7.3.5.2: Defining input variables

While most of our environmental variables were in a form amenable to initial consideration within a PCA, this was not true of our aspect variable (*Wsaspgr2*) which was recorded in terms of compass direction. This is unsuitable for PCA which simply focuses on linear correlations so that values of 1° and 359° would be interpreted as very different rather than virtually identical. The solution adopted was to calculate both the sine and cosine of aspect (*Sinasp* and *Cosasp* respectively) and include these variables in the PCA instead. The combination of these two transformations allows aspect to be interpreted in linear terms.

When an initial attempt was made to undertake PCA using the FACTOR command of SPSS-X, a warning message of the form 'ill conditioned data matrix' was encountered (though results were generated). Further investigation suggested that this situation might reflect either:

i. variables with a very small coefficient of variation (e.g. <0.002%)

or ii. high correlations between a number of the input variables.

Subsequent calculations suggested that the former was unlikely to be a problem (see Table 7.5) but that the latter might well be. It is almost ironic that while PCA searches out for relationships between variables, if some of these are extremely strong then calculation problems can arise. To investigate this possibility Pearson correlations matrices were calculated for both Sitka spruce and beech datasets of environmental variables (see Appendix 5.2). Inspection of these results identified five groupings of correlated variables as follows:

Group 1:	*Acctemp; Growseas; Grazseas
Group 2:	*Rainfall; RetWet; *RetMed; RetDry; *FcapDays; EndWet; *EndMed; EndDry
Group 3:	*MdefGra; MdefCer; MdefSbpt
Group 4:	*AvwatGra; AvwatCer; AvwatPot
Group 5:	AutMWD; *SprMWD

Within each of these groups, one or more (depending upon the degree of correlation) variables were chosen to be entered into the PCA (marked * above). Choice of 'input' variable depended upon the biological plausibility of a relationship with YC, the degree of correlation with other variables and the consequent requirement that the resultant data matrix should not be ill-conditioned. All these conditions were satisfied. In addition to the above seven, further less correlated input variables were also identified for inclusion within the PCA (*Workabil, Wselvgr2, Dsl2, Topex1km, Wind1km2, Cosasp, Sinasp*).

This analysis resulted in a consistent list of predictor variables for both our Sitka spruce and beech datasets with the single exception of AutMWD and SprMWD, both of which could be included for spruce but not beech. As it was considered important to use the same set of variables for each species, the weaker AutMWD variable was deleted from both PCA studies.

7.3.5.3: PCA for Sitka spruce environmental variables

i. Examining the correlation matrix

The first task was to calculate the degree of sampling adequacy for both individual variables and the entire sample. This shows the extent to which individual variables can be explained by other variables and the extent to which factors describing the variation of the overall dataset can be created. With respect to the entire sample this is given by the Kaiser-Mayer-Olkin (KMO) measure of sampling adequacy. KMO compares the magnitude of observed correlation coefficients to partial correlation coefficients. If partial correlations are relatively high then KMO will be low suggesting that correlations between pairs of variables cannot be explained by other variables. Conversely when partial correlation coefficients are low, KMO is high and communality is high. KMO ranges from 0 (totally inadequate) to 1 (perfectly adequate) with values below 0.5 indicating samples for which PCA is inappropriate. Calculating KMO for the Sitka spruce dataset gave a value of 0.76 which Kaiser (1974) describes as middling to meritorious. Sampling adequacy for individual variables was confirmed through inspection of the anti-image correlation (AIC) matrix (see Appendix 5.2 for details).

ii. Component extraction

Here linear combinations of the variables are formed. The first principal component (or factor) will be that which accounts for the largest amount of variance in the data. The second factor accounts for a lesser amount of variation and is uncorrelated with the first. We can carry on defining factors up to the number of variables in the sample but this would be a rather pointless exercise. Therefore we need to consider the amount of variation explained by each factor and devise some rule to determine where we will draw the line with respect to the minimum number of factors to which we can reduce our input variables. The most common approach is to standardise all variables and factors with a mean of zero and variance of one. This will mean that the total standardised variance of the sample will be equal to the number of input variables, here 15. The total amount of standardised variance explained by any one factor (known as its eigenvalue) can then be compared to the total standardised variance of the sample and the percentage variance explained calculated.

Factors which have eigenvalues of less than 1 perform less well than simple variables (which are constrained to have a standardised variance of 1) and so this is commonly used as a cut-off point below which factors are discarded. In this case the first five factors all satisfy this criteria and account for 76.9% of the total variance in the sample.

iii. Improving interpretability: factor rotation

Interpretation of the factors may be achieved by calculating a 'factor matrix' detailing the correlation coefficient or 'component loading' between each factor and each variable. This is then 'rotated' using the 'varimax' method of Kaiser (1958) to minimise the number of variables having a high loading on each factor thereby enhancing the interpretability of each factor. Table 7.6 details component loadings for our rotated factor matrix.

Table 7.6: Rotated factor matrix: Sitka spruce sub-compartments

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Acctemp	-0.34	0.15	-0.28	-0.59	-0.38
Rainfall	0.92	0.20	0.13	0.08	-0.06
RetMed	-0.94	-0.14	-0.18	-0.09	0.05
EndMed	0.91	0.20	0.17	0.13	-0.05
FcapDays	0.94	0.15	0.17	0.06	0.05
MdefGra	-0.77	0.11	-0.14	-0.19	-0.22
AvwatGra	0.16	-0.04	0.88	-0.04	-0.04
Workabil	0.19	-0.10	0.87	-0.03	-0.06
SprMWD	-0.51	0.27	0.12	0.15	-0.16
Wselvgr2	0.16	-0.38	0.51	0.41	0.38
Dsl2	0.10	0.73	0.06	0.06	0.31
Topex1km	0.21	0.81	-0.07	0.02	0.04
Wind1km2	0.00	-0.78	0.36	0.18	0.23
Cosasp	-0.03	0.13	-0.09	-0.10	0.81
Sinasp	0.07	0.05	-0.16	0.84	-0.22

Inspection of the PCA factors detailed in Table 7.6 indicated that they were relatively easy to interpret as follows:

Factor No.	Label
1	Soil wetness/rainfall
2	Steeper slopes/low windiness
3	Waterlogging/workability/high elevations
4	Cold/sine aspect
5	Cosine aspect/elevation

The 'communality' or proportion of variance in each input variable which is 'explained' by the five factors[20] was also calculated. This indicated that the only variable which is relatively poorly explained is sprMWD (communality = 0.39), all other variables having a reasonable proportion of variance explained by our five factors (mean communality = 0.80).

iv. Calculating factor scores

The factor score coefficient matrix was calculated via the regression method described by Norusis (1985)[21]. Factor scores (which indicate the position of each observation (here each sub-compartment) on the extracted, rotated factors) were then calculated in the normal manner (Appendix 5.2 gives examples for both our Sitka spruce and beech factor matrices). The site specific factor scores obtained by this process can then be entered directly into our YC regression model as the environmental explanatory variables.

7.3.5.4: PCA for beech environmental variables

The PCA procedure applied to the beech sub-compartments was identical to that used for the Sitka spruce sites and so results will be presented in brief.

i. Examining the correlation matrix

The KMO measure of sampling adequacy was calculated to be 0.77, a figure similar

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[20] The communality is the sum of the squared factor loadings.

[21] This is the default method in SPSS-X.

to that for Sitka spruce. Inspection of the AIC matrix for beech. Generally these are indicated that sampling adequacy for individual variables was generally as desired for a successful PCA although the individual values for Avwatgra and Workabil were rather lower than for Sitka spruce (see Appendix 5.2 for details).

ii. *Component extraction*

As before five factors satisfied our criteria for extraction.

iii. *Improving interpretability: factor rotation*

A rotated factor matrix was calculated as before and is detailed in Table 7.7.

Table 7.7: Rotated factor matrix: beech sub-compartments

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Acctemp	-0.44	-0.60	0.06	-0.38	-0.01
Rainfall	0.94	0.03	0.02	0.19	0.03
RetMed	-0.96	-0.09	-0.03	-0.15	-0.02
EndMed	0.94	0.08	0.04	0.29	0.04
FcapDays	0.96	0.10	0.05	0.16	0.02
MdefGra	-0.85	-0.35	0.05	-0.14	0.12
AvwatGra	-0.03	0.02	0.95	0.03	0.02
Workabil	0.10	0.01	0.92	-0.07	-0.14
SprMWD	-0.74	-0.22	-0.06	0.14	0.17
Wselvgr2	0.16	0.89	0.04	0.16	0.06
Dsl1	0.19	0.07	-0.00	0.77	0.04
Topex1km	0.51	-0.14	-0.03	0.65	-0.05
Wind1km2	0.11	0.83	0.04	-0.42	-0.05
Cosasp	-0.15	0.17	-0.13	0.39	-0.65
Sinasp	-0.19	0.14	-0.11	0.24	0.77

We can interpret these rotated factors as follows:

Factor No.	Label
1	Soil wetness/rainfall
2	High elevation/cold/windiness
3	Waterlogging/workability
4	Steep slopes/low windiness
5	Aspect

Communality coefficients were calculated. These were relatively high for all input variables, none having values under 0.60 (mean communality = 0.81).

iv. *Calculating factor scores*

Factor scores were calculated as discussed previously.

7.4 YIELD MODELS FOR SITKA SPRUCE

In this section we present details for the various regression models estimated for prediction of Sitka spruce YC. Further details regarding the regression models estimated as well as accompanying correlation matrices and descriptions of the base data are given in Appendix 5.3.

Three types of model were fitted. These varied according to whether the environmental characteristics of a site were described by: (i) raw data; (ii) factors for our PCA; (iii) a mixture of these two (ensuring that raw variables retained in the model were not significantly correlated with retained factors). Clearly these latter mixed models are invalid if the site characteristic being described by a particular factor is also being explained by a raw data variable. For example *Factor 1*, which represents (for our Sitka spruce sub-compartment) soil wetness and rainfall could not be included within the same model as the raw variable *Rainfall*. However, we wished to test whether some site characteristics might be better described by factors while, within the same model, other uncorrelated characteristics could be optimally described by raw variables. Our initial dataset for Sitka spruce contained a number of sites for which YC or other key data was missing and so these sites were deleted to leave an initial complete dataset of 6082 sites. This is far larger than any of the studies considered in our literature review and demonstrates one of the principal advantages of our large database approach compared to more common analyses based upon small site surveys.

Our regressions analyses followed the approach set out by Lewis-Beck (1980) and Achen (1982). An initial objective concerned the identification of an appropriate functional form for our models. These indicated that a linear model performed marginally better than other standard forms and, given that such a form is both easily interpretable and typical of other studies, this seemed a sensible choice.

Initial comparison across the factor only, variable only and mixed model types suggested that there was little difference in the degree of explanation afforded by these various approaches but that the mixed model performed marginally better than the others and is reported as Model 7.1. Inspection of this model shows that the large sample size has permitted the identification of a large number of highly significant predictors many of which conform to prior expectations. With respect to the environmental characteristics of sites we can see that YC falls with increasing rainfall (*Rainfall*), elevation (*Wselvgr2*) and cosine aspect (*Factor 5*) and rises with low windiness (*Factor 2*).

Model 7.1: Initial regression model for Sitka spruce (mixed model)

Predictor	Coef	Stdev	t-ratio	p
Constant	17.0792	0.2482	68.83	0.000
Rainfall	-0.00177733	0.00008489	-20.94	0.000
Wselvgr2	-0.0070769	0.0003906	-18.12	0.000
Factor 2	0.07469	0.03586	2.08	0.038
Factor 5	-0.16595	0.03365	-4.93	0.000
Soil23	0.89814	0.06729	13.35	0.000
Soil1	-4.9538	0.7437	-6.66	0.000
Area	0.0037050	0.0003260	11.36	0.000
Plantyr	0.030379	0.002682	11.33	0.000
1st Rot	-1.52753	0.08576	-17.81	0.000
MixCrop	-0.21314	0.06524	-3.27	0.001
Park	0.91121	0.07692	11.85	0.000
Ancient	1.1777	0.2783	4.23	0.000
Uncleared	2.4639	0.1808	13.63	0.000
Unprod	-0.076776	0.007079	-10.85	0.000
Reserve	-0.36615	0.07685	-4.76	0.000
Semi-nat	-4.5487	0.5983	-7.60	0.000

s = 2.297 R-sq = 40.9% R-sq(adj) = 40.7%

Analysis of Variance

Source	DF	SS	MS	F	p
Regression	16	22122.7	1382.7	262.10	0.000
Error	6062	31978.7	5.3		
Total	6078	54101.4			

Because of its discrete nature, soil type is considered as a series of dummy variables, two of which proved statistically significant. YC is significantly elevated by planting on brown earth or podzol soils (*soil23*, which is a simple combination of *soil2* and *soil3*) and significantly depressed by planting on lowland lithomorphs (*soil*). Both results conform to prior expectations.

The model also highlights the importance of silvicultural factors. The positive relationship with the size of the plantation (*Area*) is interesting and, to our knowledge, has not been formally identified before. This would seem to indicate that trees which are part of large plantations are more likely to thrive than those in small areas. This might be because large stands provide advantages in terms of the ease of adopting species specific management regimes, or because such stands tend to condition their environment to their own advantage (for example, by reducing competition from both flora and fauna). Conversely this latter factor may be one of the pressures mitigating against smaller stands. The strong and positive influence of the time variable (*plantyr*) is confirmed. This is usually explained as reflecting improvements in silvicultural methods such as the introduction of ploughing and fertilisers and/or improvements in the genetic stock[22].

Two further silvicultural factors are identified. Trees planted on ground which has not been previously used for afforestation (*1st Rot*) perform relatively worse than those planted in successive rotations. This may be because second rotation trees have on average been planted more recently than those in the first rotation (although the relatively low correlation with plantyr indicates this may not be all of the story) or that second rotation trees inherit a nutrient enriched soil base from their forbears. Trees also seem to perform less well when grown in a mixed species plantation (*MixCrop*) than in monoculture, a finding which suggests that there may be a timber productivity benefit associated with the amenity cost of the latter.

Next, a number of site factors which arise from the interaction of environmental characteristics and management practice were identified. YC is significantly higher in parkland areas (park), a result which may reflect more careful silvicultural management. The result that planting in areas which were previously ancient woodland (*ancient*) boosts tree growth seems to be the corollary of the impact of *1st Rot*. A further and rather interesting boost to growth is implied by the variable *uncleared* which identifies trees growing in areas which have been previously affected by windblow but have not yet been cleared. It seems that the surviving trees actually profit from windblow in that their immediate neighbours (and competitors) are removed thus boosting their access to nutrients. However, while growth rate may benefit from such events, the ensuing lack of cover raises the probability that the survivors will subsequently fall victim to windblow themselves.

[22]A counter explanation, given by a senior FC official who shall be nameless, is that this effect may also arise out of errors in the YC tables.

Finally, three negative environmental/management factors are identified. Plantations with higher amounts of unproductive land (*unprod*) not surprisingly perform relatively worse than otherwise similar others. Sub-compartments which fall within the boundaries of conservation areas (*reserve*) also exhibit relatively lower YC, as do areas which are allowed to remain as semi-natural habitat (*semi-nat*); results which may reflect the application of less intensive silvicultural techniques in such areas.

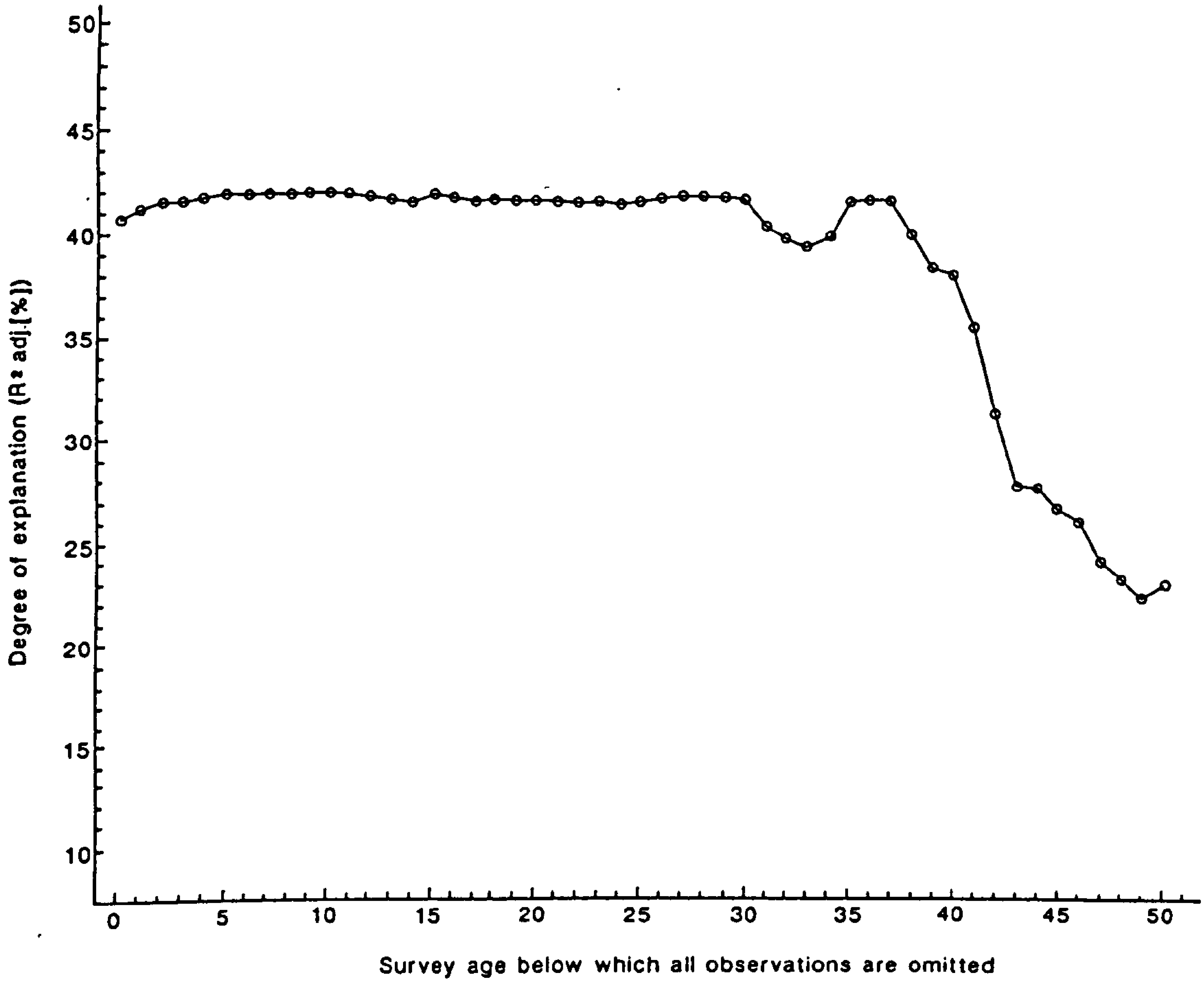
Conversations with a number of forestry experts[23] suggested that model fit might be improved by omitting those stands where YC measurements had been taken relatively soon after planting. The assessment of YC is particularly difficult in the early years of a rotation and our hypothesis is therefore that such observations are likely to have higher variance than those taken from more mature stands. To test this hypothesis a survey age variable (*sage*) was calculated from the planting year (*plantyr*) and YC survey year (*survyr*) data previously described. Sub-compartments were iteratively removed from the dataset and on each iteration Model 7.1 was re-estimated. Figure 7.1 illustrates the resulting impact upon the fit of the model (R^2-adj) of this progressive truncation of survey age (Appendix A5.3 reports precise values).

Close inspection of Figure 7.1 confirms the expected (although small) increase in model fit as stands surveyed at a very early age are removed. Omitting all observations with a survey age of less than ten years seems a reasonable assumption which still leaves us with 5168 observations. All three model variants were re-estimated from scratch[24] and the no factor model found to provide the most clearly interpretable results as reported in Model 7.2. We also use this model to provide an interesting aside regarding the effect of aspect upon tree growth. This is achieved by including the variable *Sinasp* and *Cosasp* in the model.

[23]These included Chris Quine and Adrian Whiteman of the FC and Douglas Macmillan of the MLURI.

[24]By which we mean the full procedure for entering variables into the model was repeated. This was necessary as we cannot be sure that the set of variables which best describes the untruncated dataset will also be optimal when all stands with a survey age of less than ten years are omitted.

Figure 7.1: The impact of omitting stands surveyed at different ages



Comparison of Model 7.2 with Model 7.1 shows that the omission of sites with *sage<10* results in a small but noticeable improvement in the overall degree of explanation. The removal of all PCA factors has allowed some new environmental variables to enter the model and we can see that as geomorphic shelter (*Topex1km*) increases so does YC. As stated, we have deliberately included *Sinasp* and *Cosasp* in the model to assess aspect effects. As these variables are only interpretable as a pair it is likely that, as a result of how variables explain variation within a regression model, one of them may appear statistically significant[25]. However, if we adopt a conventional 5% confidence test then neither of these aspect variables appear significant. Nevertheless, it is clear that we do not have to relax such a test by too much before aspect does appear to be having a significant effect.

[25]Intuitively one of these two may absorb the variation due to aspect so that it appears that there is little for the other to explain. However, entered separately the variables would be meaningless.

Model 7.2: YC model for Sitka spruce after omitting stands with survey age <10 years

Predictor	Coef	Stdev	t-ratio	p
Constant	16.6333	0.2697	61.66	0.000
Rainfall	-0.00176521	0.00009584	-18.42	0.000
Wselvgr2	-0.0084288	0.0003633	-23.20	0.000
Topex1km	0.025931	0.006818	3.80	0.000
Sinasp	0.7872	0.4540	1.73	0.083
Cosasp	-0.6841	0.45792	-1.49	0.137
Soil23	0.82527	0.07273	11.35	0.000
Soil1	-4.8614	0.7504	-6.48	0.000
Area	0.0038847	0.0003639	10.67	0.000
Plantyr	0.050639	0.003230	15.68	0.000
1st Rot	-1.7636	0.1005	-17.56	0.000
MixCrop	-0.28948	0.06928	-4.18	0.000
Park	0.86170	0.08295	10.39	0.000
Ancient	0.9345	0.2985	3.13	0.002
Uncleared	2.4261	0.1821	13.32	0.000
Unprod	-0.086657	0.007912	-10.95	0.000
Reserve	-0.44077	0.08421	-5.23	0.000
Semi-nat	-4.6318	0.7299	-6.35	0.000

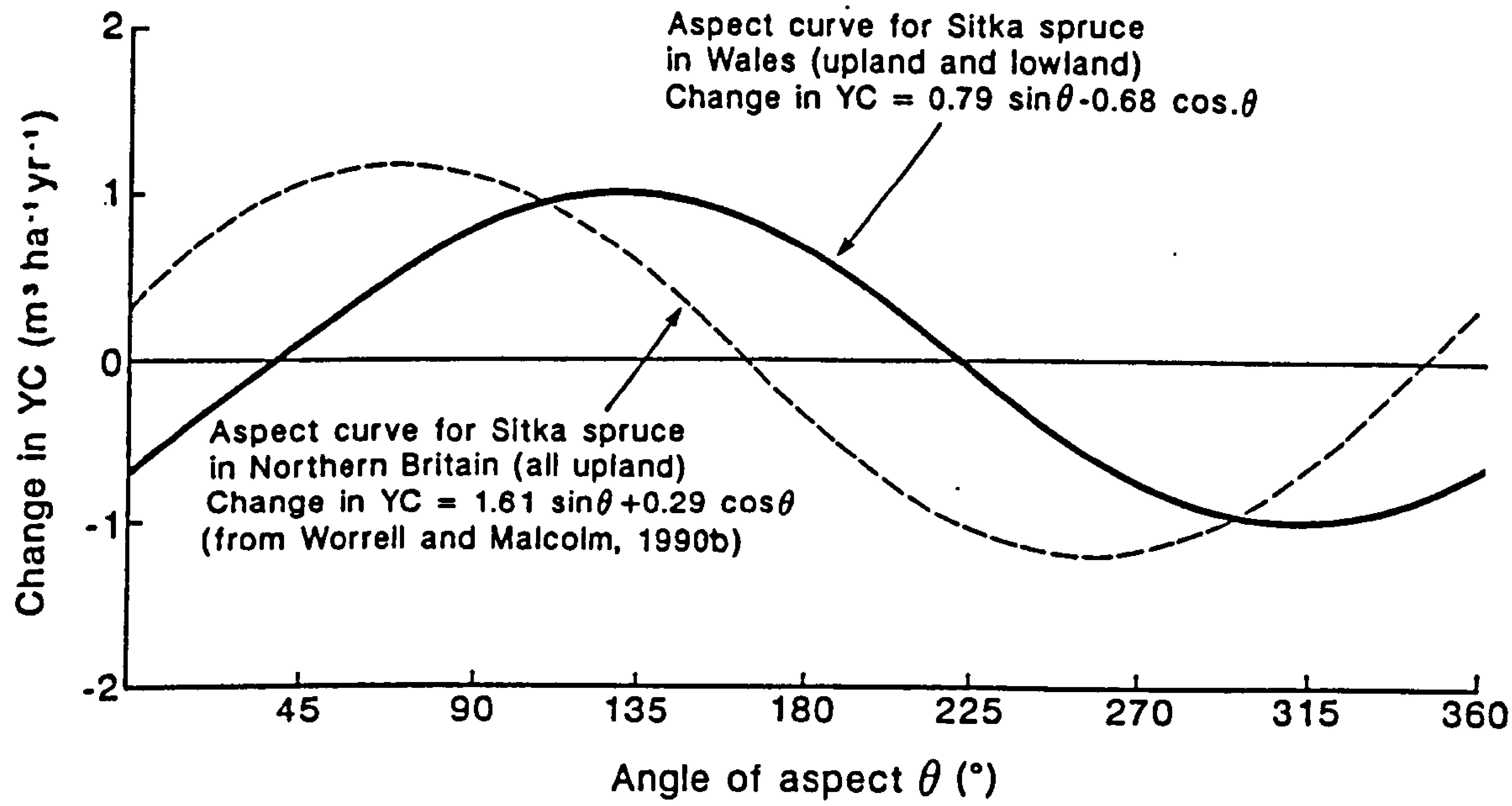
s = 2.306 R-sq = 42.1% R-sq(adj) = 41.9%

Analysis of Variance

Source	DF	SS	MS	F	p
Regression	17	19921.2	1171.8	220.30	0.000
Error	5150	27394.0	5.3		
Total	5167	47315.1			

If we temporarily accept that some weak aspect effect is occurring then we can use the coefficients given in Model 7.2 to see what this is. Figure 7.2 illustrates this predicted impact and compares our result with that of Worrell and Malcolm (1990b) from their study of Sitka spruce growing on upland sites in northern Britain.

Figure 7.2: The effect of aspect upon YC



The comparison of our results with those of Worrell and Malcolm (1990b) proves interesting. The magnitude of aspect impacts is slightly higher in the latter study, a result which is not surprising given the relatively more adverse conditions of upland areas in northern Britain. However, the most striking feature is the subtle shift in the direction of aspect effects between these two studies. Worrell and Malcolm report that YC is most severely depressed on west facing sites and highest on eastern slopes. This complete negation of any effect which increased solar radiation from the south might seem to be due to the clearly powerful impact which the prevailing westerly wind has upon such sites. Considering our own results we can see that here the aspect effect has shifted round to the south somewhat so that in Wales it is south east facing sites which appear to do best. It would seem that the relatively less adverse conditions of Wales mean that the southern solar energy effect is not completely cancelled out by the prevailing west wind. Nevertheless it is still the effect of that wind which makes a south easterly facing site outperform one which faces south west.

Returning to consider Figure 7.1, while there does appear to be an increase of fit from omitting site surveyed at a young age that sub-compartments surveyed in their prime are relatively well predicted, there is a comparatively dramatic fall in fit which occurs when we confine ourselves to only examining sub-compartments in which YC surveying occurred very many years after planting. This does not seem to be a product of the smaller sample size of such analyses as we are still considering many hundreds of sites (indeed, as sample size falls, the relatively large number of predictors in the model would tend to inflate goodness of fit statistics)[26]. Two reasons may in part account for this effect, both of which arise from the observation that, as we restrict ourselves to older survey age, we are in turn restricting ourselves to older stands. First, improved silvicultural methods, now applied to virtually all new stands, may well have been applied in a less uniform manner to such older stands. New techniques may not have been simultaneously adopted for all plantations but rather tried on a subset of these. The result would be, as observed, that these older stands are more variable than younger ones. Secondly, it may be that records regarding planting age are relatively less reliable for older stands. As YC is a function of plantation age then if this becomes uncertain so the variability of YC estimates will increase. Comparison with our subsequent analysis of beech sub-compartments suggests that there may be some merit in this argument to which we shall return.

Whatever the reason it seems that omission of those stands with relatively old survey ages is likely to further improve the fit of our model. A sensitivity analysis suggested that omission of site with survey age above 36 years resulted in an optimal fit for our models while still leaving us with some 4307 sub-compartments in our sample. As before models were rebuilt afresh to allow for the possibility of new explanatory variables better describing this revised dataset. As before the aspect variables exhibited somewhat suspect levels of significance and were accordingly omitted from these final models.

All three model types were estimated. Model 7.3 reports results from our model which describes site environmental characteristics via PCA factors. While this is of interest and all relationships conform to prior expectations it is outperformed by both our no-factor and mixed models which performed equally as well as each other. This is an interesting finding suggesting that the PCA approach used by Macmillan (1991) may not provide any significant improvement over the more widespread conventional regression models used by Worrell (1987a,b), Worrell and Malcolm (1990a,b) and also, in his more recent work, Macmillan (Tyler, Macmillan and Dutch, 1995, 1996)[27].

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[26]Indeed in Appendix A5.3 the series of truncations is extended until this effect starts to increase R^2 statistics.
[27]This study concerns species other than those under investigation and is consequently omitted from our literature review.

Model 7.3: Optimal PCA factor model for Sitka spruce: observations with *sage*<10 or *sage*>36 omitted

Predictor	Coef	Stdev	t-ratio	p
Constant	11.8800	0.3090	38.45	0.000
Factor 1	-0.70932	0.04135	-17.15	0.000
Factor 2	0.29481	0.04177	7.06	0.000
Factor 3	-0.92229	0.06664	-13.84	0.000
Factor 4	-0.23857	0.03667	-6.51	0.000
Factor 5	-0.40778	0.03685	-11.07	0.000
Soil23	0.0441	0.1366	0.32	0.747
Soil1	-4.2384	0.9869	-4.29	0.000
Area	0.0036537	0.0003872	9.44	0.000
Plantyr	0.049234	0.004954	9.94	0.000
1st Rot	-2.0853	0.1117	-18.67	0.000
MixCrop	-0.26907	0.07848	-3.43	0.001
Park	0.80303	0.09635	8.33	0.000
Ancient	0.8805	0.3171	2.78	0.006
Uncleared	2.7353	0.2329	11.75	0.000
Unprod	-0.086739	0.008315	-10.43	0.000
Reserve	-0.42987	0.09636	-4.46	0.000
Semi-nat	-4.3591	0.7831	-5.57	0.000

s = 2.372　　R-sq = 40.4%　　R-sq(adj) = 40.1%

Analysis of Variance

Source	DF	SS	MS	F	p
Regression	17	16342.51	961.32	170.86	0.000
Error	4289	24131.05	5.63		
Total	4306	40473.56			

Given the very similar performance of our no-factor and mixed models, the former is preferred for ease of interpretation and is reported as Model 7.4. The optimal list of predictor variables was found to be as before and this lack of change in model specification between truncation options gives some added weight to overall validity.

Model 7.4: Best fit YC model for Sitka spruce: no PCA factors used, observations with *sage*<10 or *sage*>36 omitted

Predictor	Coef	Stdev	t-ratio	p
Constant	16.7097	0.3487	47.92	0.000
Rainfall	-0.0016700	0.0001067	-15.65	0.000
Wselvgr2	-0.0087750	0.0003933	-22.31	0.000
Topex1km	0.024262	0.007592	3.20	0.001
Soil23	0.80489	0.08046	10.00	0.000
Soil1	-4.8827	0.9660	-5.05	0.000
Area	0.0039518	0.0003788	10.43	0.000
Plantyr	0.049890	0.004838	10.31	0.000
1st Rot	-1.9280	0.1093	-17.64	0.000
MixCrop	-0.30832	0.07670	-4.02	0.000
Park	0.94769	0.09385	10.10	0.000
Ancient	0.9266	0.3089	3.00	0.003
Uncleared	2.6411	0.2276	11.61	0.000
Unprod	-0.085426	0.008143	-10.49	0.000
Reserve	-0.43395	0.09452	-4.59	0.000
Semi-nat	-5.1415	0.7644	-6.73	0.000

s = 2.319 R-sq = 43.0% R-sq(adj) = 42.8%

Analysis of Variance

Source	DF	SS	MS	F	p
Regression	15	17391.3	1159.4	215.54	0.000
Error	4291	23082.2	5.4		
Total	4306	40473.6			

For the purposes of extrapolation Appendix A5.3 gives descriptive statistics for all the explanatory variables in all models. The appropriateness of using our best fit model for such extrapolation was assessed by comparing predicted with actual YC for the 4307 observations in our revised dataset. Results of this analysis are presented in Table 7.8 which shows that 76.5% of YC predictions are within one division of actual YC[28].

[28]This is a higher degree of accuracy than that achieved by the thematic mapper approach of Gemmell (1995) who reports that roughly 75% of predictions were within 25% of actual growth rate. Here we have over 75% of predictions within 20% of actual, with no predictions in excess of 40% of actual.

Table 7.8: Comparing actual with predicted YC for our best fit YC model of Sitka spruce (cell contents are counts)

	Predicted YC									
Actual YC	4	6	8	10	12	14	16	18	20	ALL
4	0	0	1	0	0	0	0	0	0	1
6	0	0	7	63	0	0	0	0	0	70
8	1	3	12	161	220	0	0	0	0	397
10	0	0	9	169	395	141	0	0	0	714
12	0	0	4	176	516	285	63	0	0	1044
14	0	0	0	90	415	276	124	33	1	939
16	0	0	0	0	201	313	179	33	1	727
18	0	0	0	0	0	152	144	45	3	344
20	0	0	0	0	0	0	41	26	3	70
22	0	0	0	0	0	0	0	1	0	1
All	1	3	33	659	1747	1167	551	138	8	4307

Predicted YC compared to actual YC	Percentage of total sample (%)
Prediction is two classes too high	12.8
Prediction is one class too high	23.4
Predicted YC equals actual YC	27.9
Prediction is one class too low	25.2
Prediction is two classes too low	11.4

7.5 YIELD MODELS FOR BEECH

The analysis of YC for beech sub-compartments followed the same methodology adopted in our investigation of Sitka spruce sites. Consequently only brief discussions of methodology are presented here with detailed results again being presented in Appendix 5.3.

Following the deletion of sites for which key data was missing (giving us a dataset of 766 observations), initial investigations again confirmed the suitability of a linear functional form for our model. However, now a no-factor model provided the best initial fit to the data as reported in Model 7.5.

Model 7.5: Initial regression model: beech

Predictor	Coef	Stdev	t-ratio	p
Constant	5.5089	0.5600	9.84	0.000
Rainfall	-0.0002490	0.0001686	-1.48	0.140
Wselvgr2	-0.0043064	0.0005302	-8.12	0.000
Avwatgra	0.003182	0.002302	1.38	0.167
Plantyr	0.008443	0.002452	3.44	0.001
Historic	0.5229	0.1067	4.90	0.000
Monument	-0.9295	0.6180	-1.50	0.133
NpAonbSa	0.4978	0.1444	3.45	0.001
OthESA	-0.4987	0.2998	-1.66	0.097
ForPark	-0.3877	0.1894	-2.05	0.041
National	1.0305	0.3223	3.20	0.001
FCconst	-0.6026	0.1468	-4.10	0.000
Soil2	0.2423	0.1323	1.83	0.067

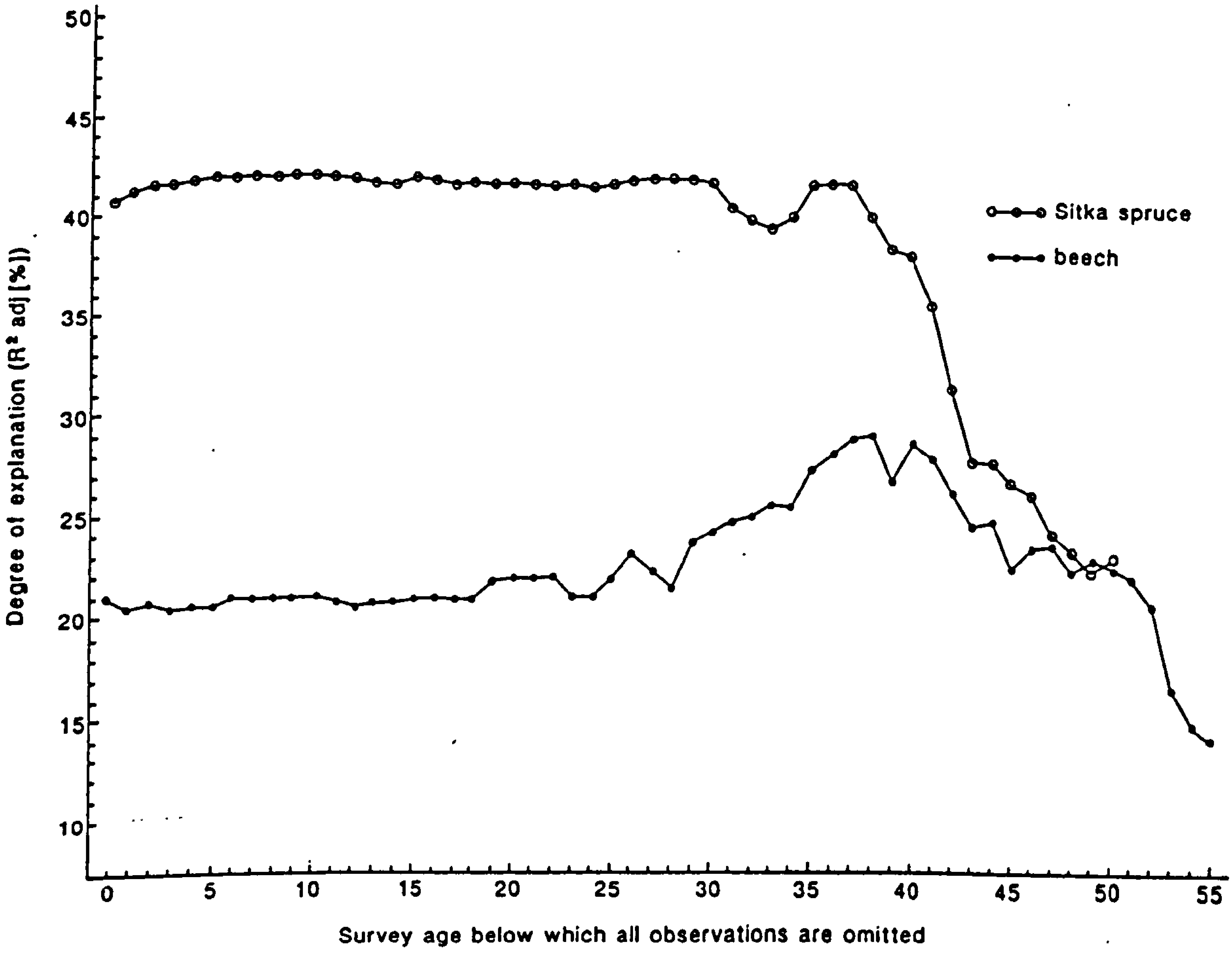
s = 1.363 R-sq = 22.2% R-sq(adj) = 21.0%

Analysis of Variance

Source	DF	SS	MS	F	p
Regression	12	399.763	33.314	17.94	0.000
Error	753	1398.070	1.857		
Total	765	1797.833			

The explanatory variables included in Model 7.5 are similar to those considered within our Sitka spruce models and so their interpretation is as before. While some of these variables are clearly rather weak, it was felt that this model provided an adequate base to analyse the impact of omitting sub-compartments on the basis of increasing survey age. This analysis was undertaken as before and results are illustrated in Figure 7.3 which for comparative purposes reproduces results from our analysis of Sitka spruce sub-compartments.

Figure 7.3: Impact upon model fit of omitting sites at successive survey age: beech and Sitka spruce



In assessing Figure 7.3 an immediate point is the relatively lower degree of fit exhibited by our models of beech growth. This is very likely to be a product of the relatively restricted range of the beech (as opposed to Sitka spruce) dependent variable discussed in Section 7.2.1. However, both curves initially rise (albeit slowly), peak and then eventually decline. Considering the curve for beech, the increase in fit from about *sage*=20 is probably due to the exclusion of stands surveyed at an early age. Note that this upward trend is much longer lasting than for our Sitka spruce analysis indicating, as expected, that it is much more difficult to assess the YC of a beech stand at say *sage*=10 than a Sitka spruce stand. Here the optimal fit excluding only low *sage* observations is achieved by omitting all sites with *sage*<38 (this compares with an optimal lower truncation at *sage*<10 for Sitka spruce). This gave a dataset of 359 observations for which model 7.6 provided the best fit.

Model 7.6: Optimal (no-factor) model for beech: sites with *sage*<38 omitted

Predictor	Coef	Stdev	t-ratio	p
Constant	4.7663	0.7357	6.48	0.000
Rainfall	-0.0001754	0.0002479	-0.71	0.480
Wselvgr2	-0.0043157	0.0007218	-5.98	0.000
Avwatgra	0.003301	0.003648	0.90	0.366
Plantyr	0.013391	0.003044	4.40	0.000
Historic	0.4699	0.1535	3.06	0.002
Monument	-0.0937	0.9340	-0.10	0.920
NpAonbSa	0.6353	0.2317	2.74	0.006
OthESAt	-0.0556	0.4753	-2.22	0.027
ForPark	-0.4153	0.2602	-1.60	0.111
National	0.4156	0.5096	0.82	0.415
FCcons	-0.3452	0.2238	-1.54	0.124
Soil2	0.2145	0.1863	1.15	0.250

s = 1.258   R-sq = 27.9%   R-sq(adj) = 25.4%

Analysis of Variance

Source	DF	SS	MS	F	p
Regression	12	211.712	17.643	11.14	0.000
Error	346	547.798	1.583		
Total	358	759.510			

Figure 7.3 also shows (as observed in our Sitka spruce data) that the degree of explanation afforded by models falls as we consider stands with relatively high *sage*, here values in excess of about 50 years seem to raise variance substantially. As previously postulated this seems likely to be connected to such stands being consequently quite old at the time of surveying. Uneven introduction of advances in silviculture may in part account for the increase in variance here. Furthermore it may be that planting date is less certain in these stands. This is more likely to be a problem with beech sub-compartments than with Sitka spruce as the latter were almost all originally planted by the FC, who generally keep good records (and may apply new silvicultural techniques in a more uniform manner), while older beech stands may have been planted by a variety of private agents for which complete and accurate planting records may not be available. Given the importance of accurate age measurements in calculating YC such uncertainty may well translate into higher variance within such stands.

Given this we felt justified in additionally omitting those stands with high *sage*. A sensitivity analysis suggested that omission of *sage* >49 would optimise the fit of our model. This gave an effective dataset of some 205 observations. Given the extent of the omission of observations, regression analysis was begun again afresh so as to redefine an appropriate set of explanatory variables. Here many variables failed to enter the model. When using our PCA approach to describing the environmental characteristics of sites only *Factor 2* proved adequately significant to enter our model which is reported as Model 7.7.

Model 7.7: Best factor-only model for beech: sites with *sage*<38 and *sage*>49 omitted

Predictor	Coef	Stdev	t-ratio	p
Constant	-5.227	1.854	-2.82	0.005
Factor 2	-0.35371	0.08458	-4.18	0.000
Plantyr2	0.08038	0.01278	6.29	0.000
AONB/NSA	0.4614	0.2719	1.70	0.091
OthESA	-1.5826	0.4941	-3.20	0.002

s = 1.266 R-sq = 35.6% R-sq(adj) = 34.3%

Analysis of Variance

Source	DF	SS	MS	F	p
Regression	4	177.140	44.285	27.65	0.000
Error	200	320.303	1.602		
Total	204	497.444			

A no-factor alternative was also estimated and is reported as Model 7.8.

Model 7.8: Optimal (no-factor) model for beech: sites with *sage*<38 and *sage*>49 omitted

Predictor	Coef	Stdev	t-ratio	p
Constant	-4.428	1.923	-2.30	0.022
Wselvgr2	-0.0038638	0.0009149	-4.22	0.000
Plantyr	0.07995	0.01279	6.25	0.000
AONB/NSA	0.4751	0.2710	1.75	0.081
OthESA	-1.4812	0.4969	-2.98	0.003

s = 1.265 R-sq = 35.7% R-sq(adj) = 34.4%

Analysis of Variance

Source	DF	SS	MS	F	p
Regression	4	177.649	44.412	27.78	0.000
Error	200	319.794	1.599		
Total	204	497.444			

Models 7.7 and 7.8 are extremely similar both in terms of their degree of explanation and their choice of explanatory variables; *Factor 1* in Model 7.7 is essentially the effect of elevation which is the raw data environmental variable *Wselvgr2* used in Model 7.8. Consequently we cannot have a mixed model for beech. Given its ease of interpretation we prefer Model 7.8 as our optimal model for predicting YC in beech sub-compartments.

An interesting supplementary analysis concerns the consideration of aspect effects. In building up our best fit model these had been investigated and rejected as insignificant. Nevertheless it is interesting to see if the logical relationship between aspect effects for Sitka spruce in northern Britain and Wales noted previously had any implications for aspect effects upon beech in Wales. The aspect variables Sinasp and Cosasp were therefore added into our best fit model which was then re-instated to produce Model 7.9.

Model 7.9: Including aspect effects within our preferred beech model

Predictor	Coef	Stdev	t-ratio	p
Constant	-4.375	1.921	-2.28	0.024
Wselvgr2	-0.0037821	0.0009141	-4.14	0.000
Sinasp	0.1203	0.1274	0.94	0.346
Cosasp	-0.1905	0.1242	-1.53	0.127
Plantyr	0.07952	0.01278	6.22	0.000
AONB/NSA	0.4856	0.2703	1.80	0.074
OthESA	-1.4455	0.5007	-2.89	0.004

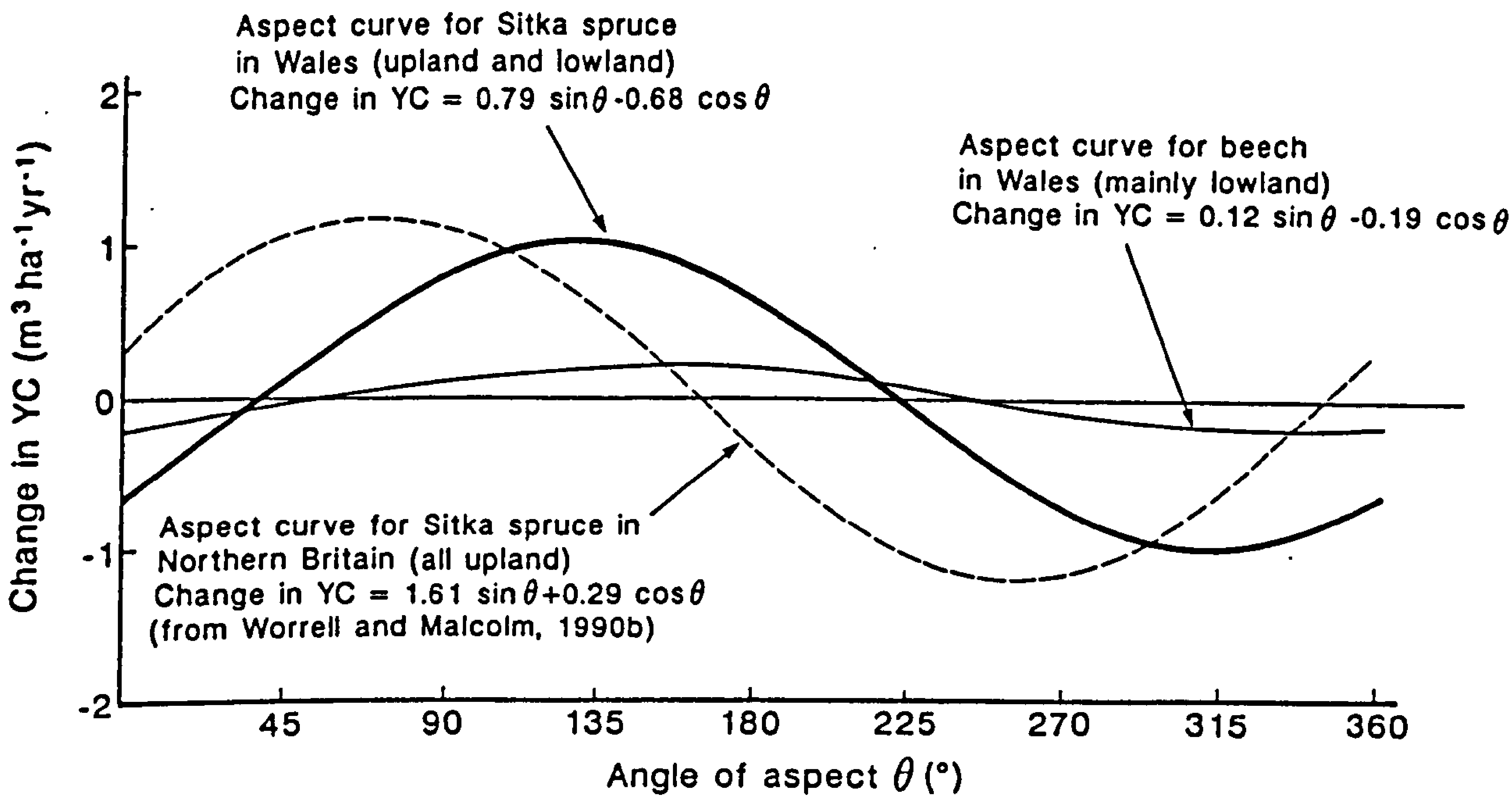
s = 1.261 R-sq = 36.7% R-sq(adj) = 34.8%

Analysis of Variance

Source	DF	SS	MS	F	p
Regression	6	182.734	30.456	19.16	0.000
Error	198	314.710	1.589		
Total	204	497.444			

As can be seen, both of the aspect variables are of very low significance. This of itself is interesting as aspect was clearly significant in the study conducted by Worrell and Malcolm (1990b) and on the edge of statistical significance in our Sitka spruce study. Similarly, consideration of coefficient estimates shows that the absolute magnitude of predicted effects was largest in the Worrell and Malcolm study, less sizeable in our Sitka spruce study and smallest here. Inspection of summary statistics given at the end of this section gives us a consistent explanation of all these results. While the Worrell and Malcolm study considered only sites in upland areas of northern Britain, or Sitka spruce analysis considers both upland and lowland sites in the less harsh climate of Wales. Furthermore comparison of descriptive statistics for our Sitka spruce and beech studies shows that beech is generally planted at significantly lower altitudes than those of Sitka spruce sites. So it seems that the impact of aspect upon tree growth depends upon altitude such that on lowland sites this may be insignificant while on upland sites aspect can have a major effect upon tree growth. Figure 7.4 superimposes the aspect curve implied by the results of Model 7.9 on to those previously described for Sitka spruce in the uplands of northern Britain (from Worrell and Malcolm, 1990b) and in the uplands and lowlands of Wales (from our models).

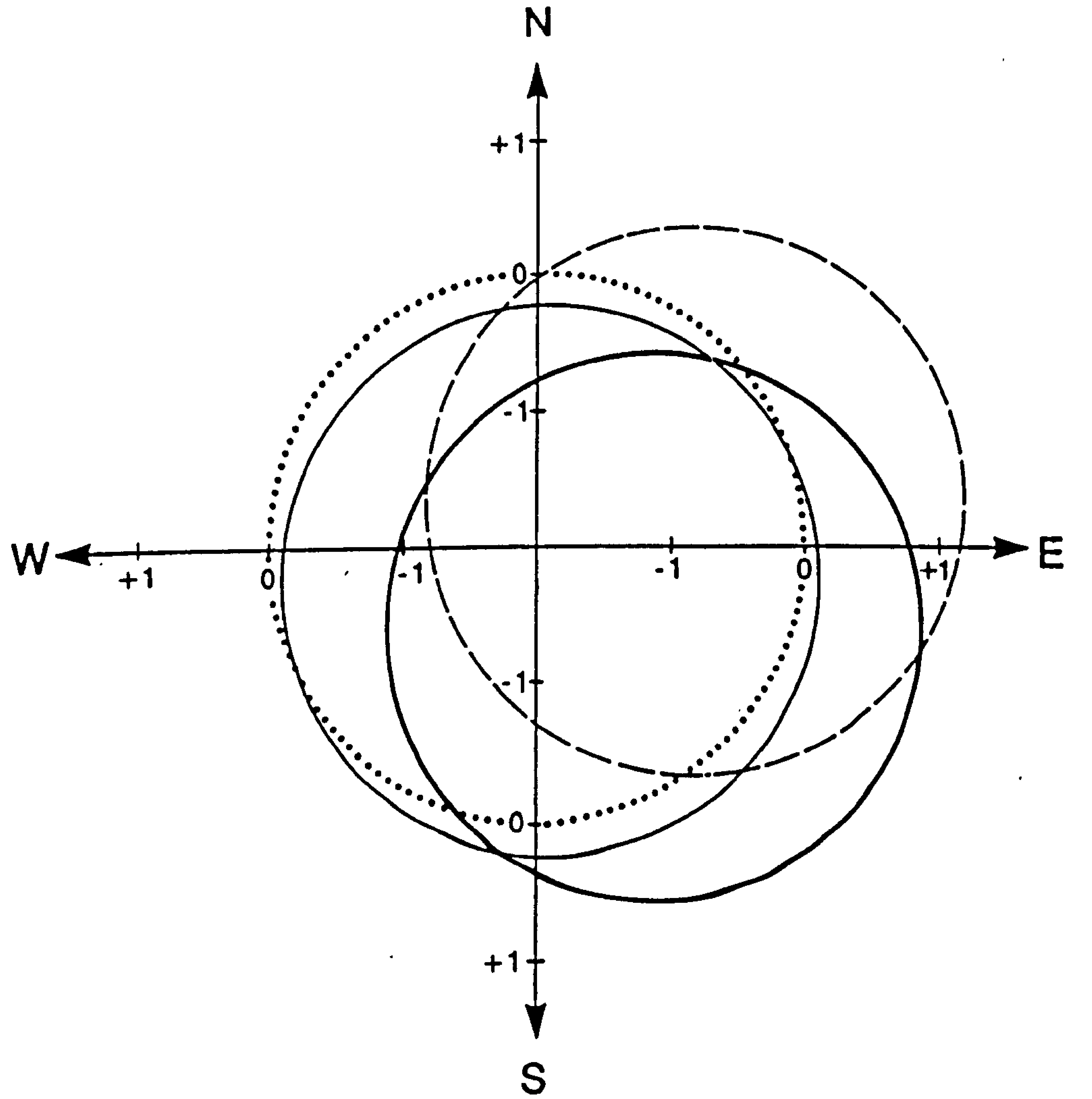
Figure 7.4: Aspect effects for Sitka spruce and beech in differing locations



Inspection of Figure 7.4 tells a clear and coherent story. In the upland areas of northern Britain the intensity of the prevailing westerly wind causes aspect to be a major factor determining tree growth such that trees in relatively sheltered east facing sites perform significantly better than those facing west. The radiative energy advantage of south facing slopes is completely negated by the impact of the prevailing wind. In our Welsh study of Sitka spruce we consider both upland and lowland sites. Here both the magnitude and statistical significance of the impact of aspect is reduced. Furthermore, the reduction in the power of the prevailing wind (induced both because we are considering sites at lower altitude and the less arduous conditions of Wales relative to northern Britain) means that the solar energy advantage of southerly sites can now be detected as our aspect effect is now maximised at south east (rather than east) facing sites. This trend is continued when we consider our beech sub-compartments. Here altitude is again substantially reduced such that the absolute magnitude and statistical significance of the aspect effect is markedly reduced. Furthermore, the reduction in the impact of the prevailing westerly wind means that the solar energy advantage of south facing is further boosted such that we find that the aspect curve for beech sites now peaks for sites facing south-south-east.

Figure 7.5 shows an alternative approach to illustrating these aspect effects. Here the basis for comparison is given by the dotted circle which is centred directly upon the compass axes. This illustrates the situation in the absence of any aspect effect with points around the perimeter of this circle showing a zero impact of aspect upon YC. The results of Worrell and Malcolm (1990b) are represented by the dashed line circle which is centred a considerable way off towards the east showing the relatively positive aspect effect of east facing sites and the negative impact of westerly sites. The extent of this displacement shows the magnitude of this aspect effect which in this case raises tree growth by a maximum of just over 1 m^3 ha^{-1} yr^{-1}. The thick solid line circle represents our results for Sitka spruce in upland and lowland Wales. Here the displacement is a little less extreme, being most positive in the south east quadrant and most negative in the north west. Finally the thinner solid line circle shows results from our analysis of beech growing in mainly lowland areas of Wales. Here the circle is only slightly displaced and shows the most positive aspect effect to be on sites facing south-south-east.

Figure 7.5: Comparison of aspect effects between Wales and upland northern Britain



Finally we can attempt to assess the validity of our best fit model (7.8) by comparing actual YC at all sub-compartments in our final dataset with YC as predicted by our model. Table 7.9 details results from this comparison.

Table 7.9: Comparing actual with predicted YC for our best fit YC model of beech (cell contents are counts)

	Predicted YC			
Actual YC	4	6	8	ALL
2	0	1	0	1
4	9	29	2	40
6	7	66	20	93
8	0	29	37	66
10	0	0	5	5
ALL	16	125	64	205

Predicted YC compared to actual YC	Percentage of total sample (%)
Prediction is two classes too high	1.5
Prediction is one class too high	23.9
Predicted YC equals actual YC	54.6
Prediction is one class too low	20.0
Prediction is two classes too low	0.0

Consideration of Table 7.9 shows that 98.5% of YC predictions are within one division of actual YC. This is a considerably higher rate of correct prediction than that achieved by our Sitka spruce model although given the restricted range for the dependent variable for beech this is perhaps not surprising and should therefore be treated with a little caution. Nevertheless, even accepting this warning, the apparent validity of the model is encouraging.

7.6 MAPPING YIELD CLASS

We have now estimated, for both of the tree species considered, two YC models, one including PCA factor explanatory variables and the other without. For our Sitka spruce dataset model 7.3 provides the best fitting PCA based model while 7.4 gives a slightly better fit without using PCA factors. Similarly for our beech dataset, model 7.7 gives the best PCA based predictions of yield while model 7.8 provides a slightly better fit without using PCA factors. These four models are used to provide estimates for the GIS images of YC presented and analysed below.

7.6.1: PRODUCING GIS IMAGES OF YIELD CLASS

In this context, an image is simply a spatially referenced depiction of a dataset produced by the GIS which can then be displayed upon a screen or printed as required. To produce a YC image the GIS requires data on all the predictor variables for all the grid points (the 'coverage') for which we want to predict, in this case the entire land area of Wales. If we take the best fitting Sitka spruce VAR model (7.4) as an example, we can see that this is predicted by a constant and a number of explanatory variables. The constant is in essence a coverage in its own right which has identical values (here 16.709) for all grid points. The first explanatory variable in this model is the predictor *Rainfall* for which we have a full coverage from the LandIS database. We can therefore build up our GIS predicted YC map by telling the software to calculate a new image being the coverage *Rainfall* multiplied by its coefficient (-0.00167). Using the Idrisi GIS this operation is performed by use of the *Scalar* command. The resultant image can then be combined with that for the constant by use of the Overlay command, which as its name suggests, in effect overlays these two images to produce a third being YC as predicted by these first two elements in the model. Subsequent predictors are incorporated in a similar manner with separate images being created by multiplying the variables coverage values by its coefficient using the *Scalar* command and then incorporating the resultant image into the YC map using the *Overlay* command.

When using the PCA based models we need to first construct component score images covering the whole of Wales. This was achieved by first creating z-score images of each of the variables considered in the PCA[29] and then using the component score coefficients calculated for Sitka spruce and beech to produce images of each factor. These were then treated as were the explanatory variables discussed above.

In all the models a number of the predictor variables are related to management (e.g. *Area*), policy (e.g. *reserve*) or when the site was planted (e.g. *plantyr*). These are not specifically spatial variables are so where treated by holding them at certain fixed values (i.e. as per the constant) and varying certain of these in a sensitivity analysis. The variables *MixCrop, ancient, unprod, reserve, park, uncleard* and *semi-nat* are all dummies for infrequently occurring, unusual sites and were consequently held at zero (their median value) for all images. Similarly the variable *Area* was held at its median value of 33 ha for Sitka spruce sites and 10 ha for beech sites. Given the very low value of the coefficient on this variable and its relatively small range (see the descriptive statistics given in Appendix 5) sensitivity analysis did not seem justified here. However, this was not the case for the variables *plantyr* and *1st Rot* and full sensitivity analyses were conducted here.

7.6.2 GIS TIMBER YIELD IMAGES FOR SITKA SPRUCE

We produced images based on both our best non-PCA and PCA based yield models. Further to this we also considered the impact of changing the plantyr variable from 0 (being the base year in which the Forestry Commission started to plant Sitka spruce) to 75 (being the present day, i.e. Sitka spruce planting commenced about 75 years ago) thereby arguably reflecting technological progress over that period[30]. For both of these analyses we initially hold 1st Rot = 1, i.e. examining first rotation trees at both of these time periods. However, many present day Sitka spruce plantations are now in their second rotation. Therefore we also test the effect of letting 1st Rot = 0 (i.e. second rotation) when plantyr = 75. This combination of differing models and assumptions resulted in 6 images being created. Table 7.10 details these images and provides a simple labelling system which we adopt subsequently.

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[29]The means and standard deviations necessary for this operation were taken from the variable values for all the forestry sub-compartments (both species). These will be somewhat different from those for the entirety of Wales but given the size of the forestry dataset, any discrepancy is liable to be minor.

[30]See our previous discussion of possible interpretations of this effect.

Table 7.10: Sitka spruce GIS timber yield class images created: image labels

Model type	plantyr= 0 1st Rot=1	plantyr= 75 1st Rot=1	plantyr=75 1st Rot=0
No PCA factors used (model 7.4)	SS1VAR	SS2VAR	SS3VAR
PCA factors used (model 7.3)	SS1FAC	SS2FAC	SS3FAC

Images were produced using the procedure outlined in section 7.6.1. Figure 7.6 illustrates the predicted YC image created from model 7.4 (no PCA factors used) with plantyr = 75 (present day) and 1st Rot = 0 (replanting on a previously planted site) i.e. image SS3VAR.

Inspection of figure 7.6 clearly shows the very strong influence which environmental characteristics have upon our predictions of YC. The influences of lower altitude, better soil and less-excessive rainfall combine to produce high YC. The pattern of lower YC produced by higher elevations is particularly noticeable with the mountain ranges of Snowdonia, the mid Cambrians and the Brecon Beacons clearly picked out. Less extreme upland areas such and the Preseli Mountains produce YC values which lie between these extremes. Also clearly noticeable is the adverse excess rain-shadow lying to the east of the Cambrians which results in large areas of relatively depressed YC values stretching in some cases up to (and across) the English border. The adverse effect of sandy and estuarine soils upon growth can also be seen in the small but significantly depressed areas of low yield at places such as the tip of the Gower Peninsula and nearby Pembrey, the southernmost part of Anglesey and the Landudno peninsula[31].

[31] Interestingly both Pembrey and Newborough (Anglesey) are the sites of large forests, underlining the point that forests are often confined to the most marginal land.

Figure 7.6: Image SS3VAR: predicted yield class from our optimal (no factor) model of Sitka spruce growth (assuming plantyr = 75; 1st Rot = 0).

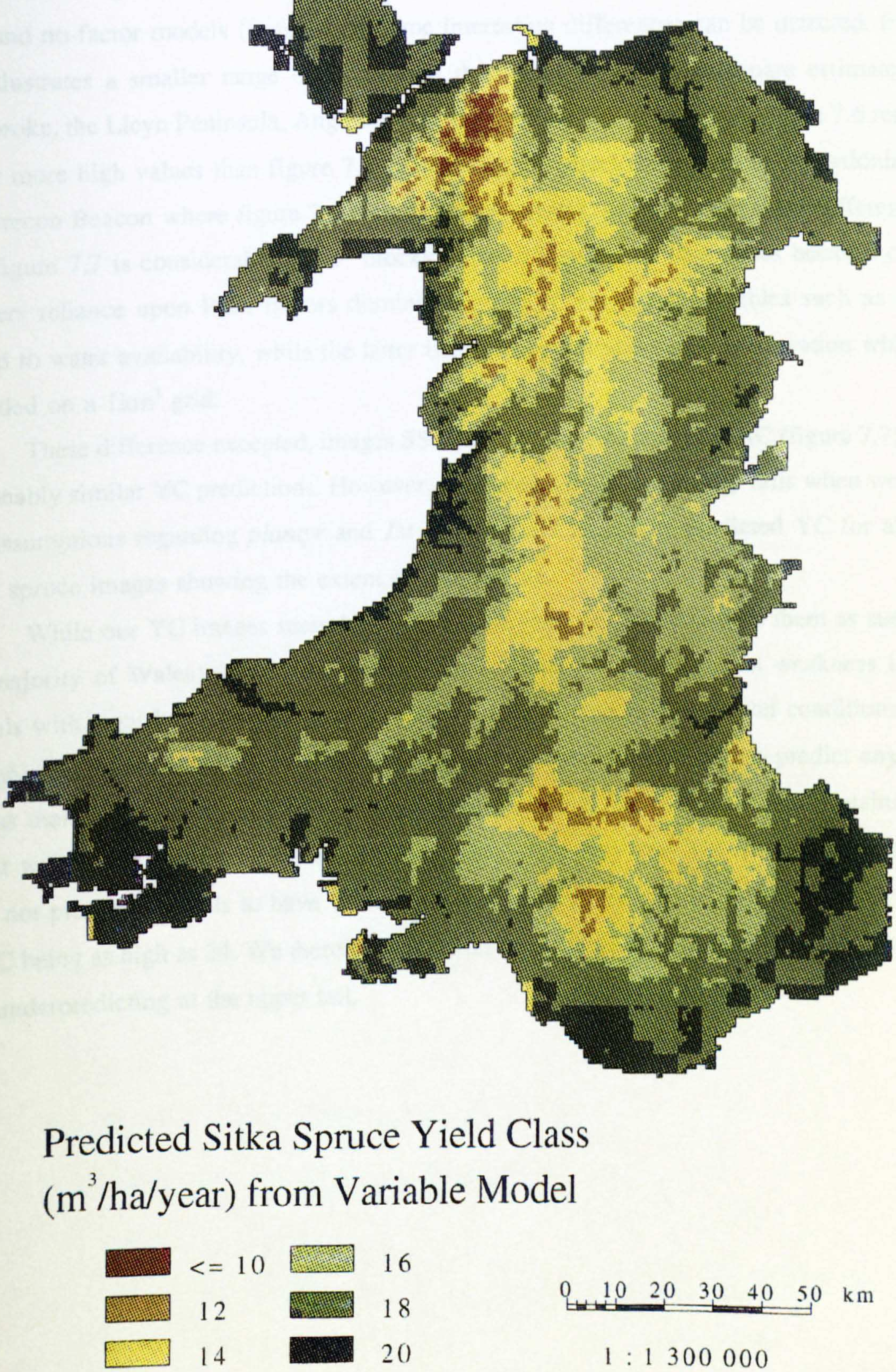

Figure 7.7 reproduces image SS3FAC, which uses the same assumptions regarding Plantyr and 1st Rot as Figure 7.6, but employs our best fitting factor based model (7.3) of YC. While the general pattern of YC predictions is similar between our factor-based (figure 7.7) and no-factor models (figure 7.6), some interesting differences can be detected. Figure 7.7 illustrates a smaller range of YC values than does figure 7.6 (compare estimates for Pembroke, the Lleyn Peninsula, Anglesey and the North Wales coast where figure 7.6 records many more high values than figure 7.7; also compare upland areas such as Snowdonia and the Brecon Beacon where figure 7.6 records lower values). Another noticeable difference is that figure 7.7 is considerably more "blocky" than is figure 7.6. This arises because of the formers reliance upon PCA factors dominated by $5km^2$ resolution variables such as those linked to water availability, while the latter is driven by variables such as elevation which is recorded on a $1km^2$ grid.

These difference excepted, images SS3VAR (figure 7.6) and SS3FAC (figure 7.7) give reasonably similar YC predictions. However, predicted YC systematically falls when we alter our assumptions regarding *plantyr* and *1st Rot.* Table 7.16 details predicted YC for all our Sitka spruce images showing the extent of this decline.

While our YC images seem highly plausible (and we would defend them as such for the majority of Wales), table 7.11 and figures 7.6 and 7.7 do indicate a weakness in our models with regard to their ability to predict YC for extreme environmental conditions such as, for example, mountain tops. Our best fitting model (SS3VAR) fails to predict any sites of less than YC6. However, clearly if trees were planted at the very tops of mountains they might well fail to survive or would at best produce only very low YC. Similarly our model does not predict any cells to have YC in excess of 20, yet our dataset indicated a few cases of YC being as high as 24. We therefore appear to be overpredicting YC at the lower extreme and underpredicting at the upper tail.

Figure 7.7: Image SS3FAC: predicted yield class from our best fitting factor based model of Sitka spruce growth (assuming plantyr = 75; 1st Rot = 0).

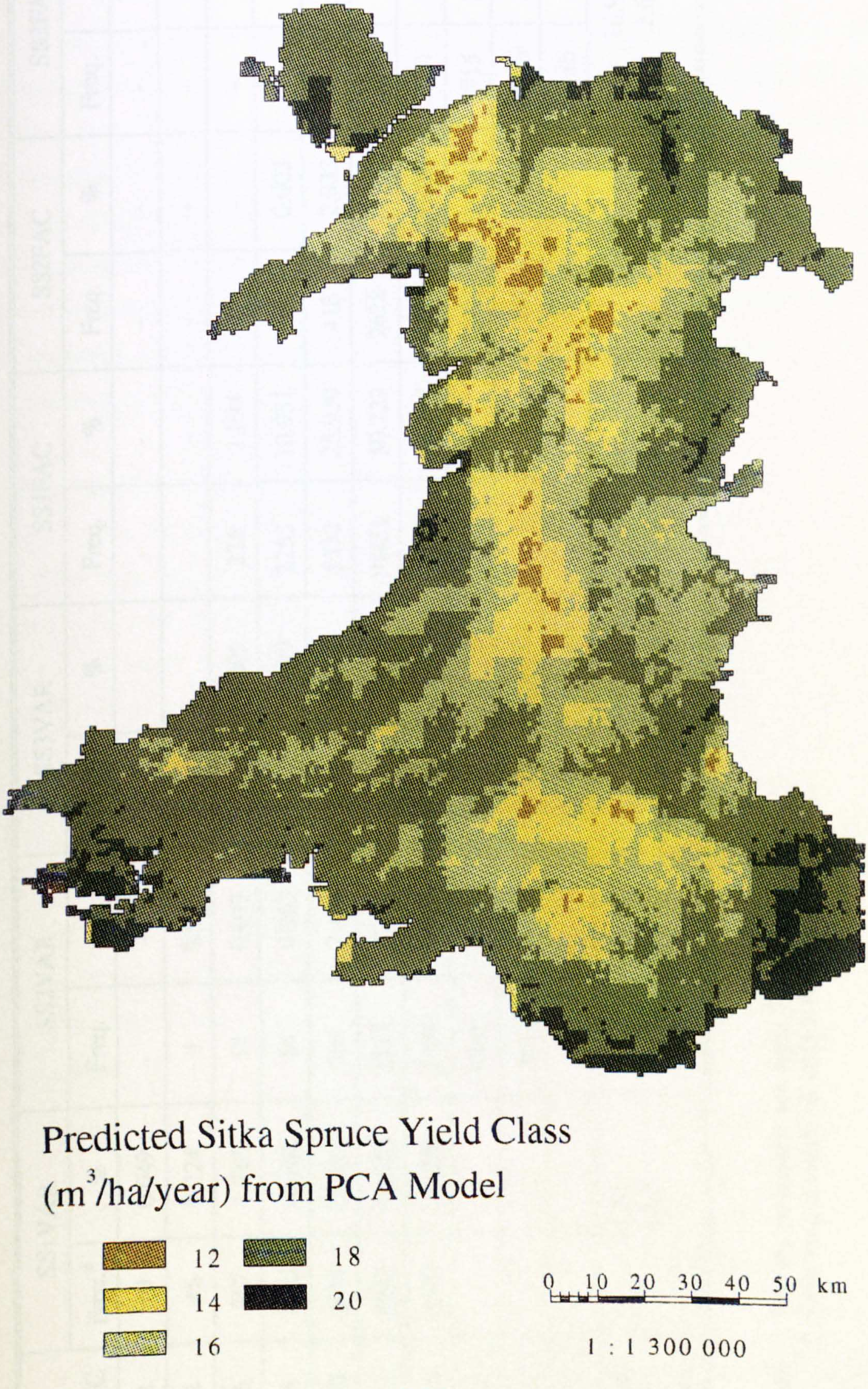

Table 7.11: Predicted timber yield class from various Sitka spruce maps[1].

YC	SS1VAR		SS2VAR		SS3VAR		SS1FAC		SS2FAC		SS3FAC	
	Freq.[2]	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
2	10	0.049	-	-	-	-	-	-	-	-	-	-
4	46	0.224	1	0.005	-	-	-	-	-	-	-	-
6	367	1.785	15	0.073	1	0.005	225	1.094	-	-	-	-
8	2255	10.966	54	0.263	16	0.079	2253	10.957	1	0.005	-	-
10	4691	22.813	504	2.451	56	0.272	5332	25.930	418	2.033	-	-
12	8747	42.538	2524	12.274	554	2.694	10431	50.727	2628	12.780	359	1.746
14	4447	21.626	5106	24.831	2609	12.688	2322	11.292	6187	30.088	2524	12.274
16	-	-	9287	45.164	5209	25.332	-	-	10182	49.516	5915	28.765
18	-	-	3072	14.939	9416	45.791	-	-	1147	5.578	10329	50.230
20	-	-	-	-	2702	13.140	-	-	-	-	1436	6.983
Mean s.d.	11.38 2.81		15.12 2.81		17.05 2.81		11.21 2.65		14.90 2.65		16.98 2.65	

Notes: 1. For key to images see table 7.10
2. Each map consists of 20563 $1km^2$ land cells.

Three factors seem pertinent in explaining this. Firstly, we are predicting average YC over a 1km^2 grid square. This will tend to remove any extremes and therefore gives some support to our findings. Secondly, and less positively, as discussed in Appendix 5, in creating our digital elevation model we were unable to fully capture the upper extremes of altitude. This means that we are under-representing elevation at the tops of mountains and therefore over-estimating YC at these points. Thirdly, as there is relatively little planting at the extremes of altitude so resultant low YC observations are relatively under-represented in the FCs sub-compartment database resulting in a lesser ability of statistical models based on such data to estimate accurately for such locations. However, while these are problems, the actual versus predicted comparison reported in table 7.8 suggests that the degree of over and underprediction at the tails is not overly serious.

7.6.3: GIS TIMBER YIELD IMAGES FOR BEECH

As before, we produced images based on both our best non-PCA and PCA based yield models. Further to this we again considered the impact of changing the *plantyr* and *1st Rot* variables. In the case of the plantyr variable, unlike our Sitka spruce analysis there was no distinct year in which beech planting commenced. Thus although we have a date at which plantyr = 0 this corresponds purely to the oldest record in the dataset (some 162 years ago) rather than to some actual initial planting date. Accordingly it was decided to adopt a somewhat different strategy here and our sensitivity analysis examined two values: plantyr = 144 (which equalled both the mean and median planting date); and plantyr = 162 (the present day). The dataset showed comparatively few beech sub-compartments were not in their first rotation and so this analysis was not performed, 1st Rot being held at a value of 1 for all beech images. The combination of factor and non-factor models and differing plantyr values yielded four different beech YC images. Table 7.12 details these images and provides labels as before.

Table 7.12: Beech GIS timber yield class images created: image labels

Model type	plantyr=144 1st Rot=1	plantyr=162 1st Rot=1
No PCA factors used (model 7.8)	BE1VAR	BE2VAR
PCA factors used (model 7.7)	BE1FAC	BE2FAC

Images were produced using the procedure outlined in section 7.6.1. Figure 7.8 illustrates the predicted YC image created from our best fit beech model 7.8 (no PCA factors used) with plantyr = 162 (present day) and 1st Rot = 1 (first rotation) i.e. image BE2VAR.

As expected the general pattern of YC predictions observed for our Sitka spruce images is repeated in our beech images with high elevation and poor soils being associated with lower YC. However, both the absolute values of YC and its range are much lower than before. This is again as expected and reflects the restricted range of beech YC values recorded in the sub-compartment database. Our comments regarding these and other limitations to these predictions are as for our discussion of the Sitka spruce images.

As for our Sitka spruce analysis, the general pattern of predicted YC for beech is reasonably consistent between images (with FAC images again being somewhat more blocky than their VAR equivalents) and so no further maps are reproduced here. However, table 7.13 presents YC results from the four images detailed in table 7.12.

Figure 7.8: Image BE2VAR: predicted yield class from our optimal (no factor) model of beech growth (assuming plantyr = 162; 1st Rot = 1).

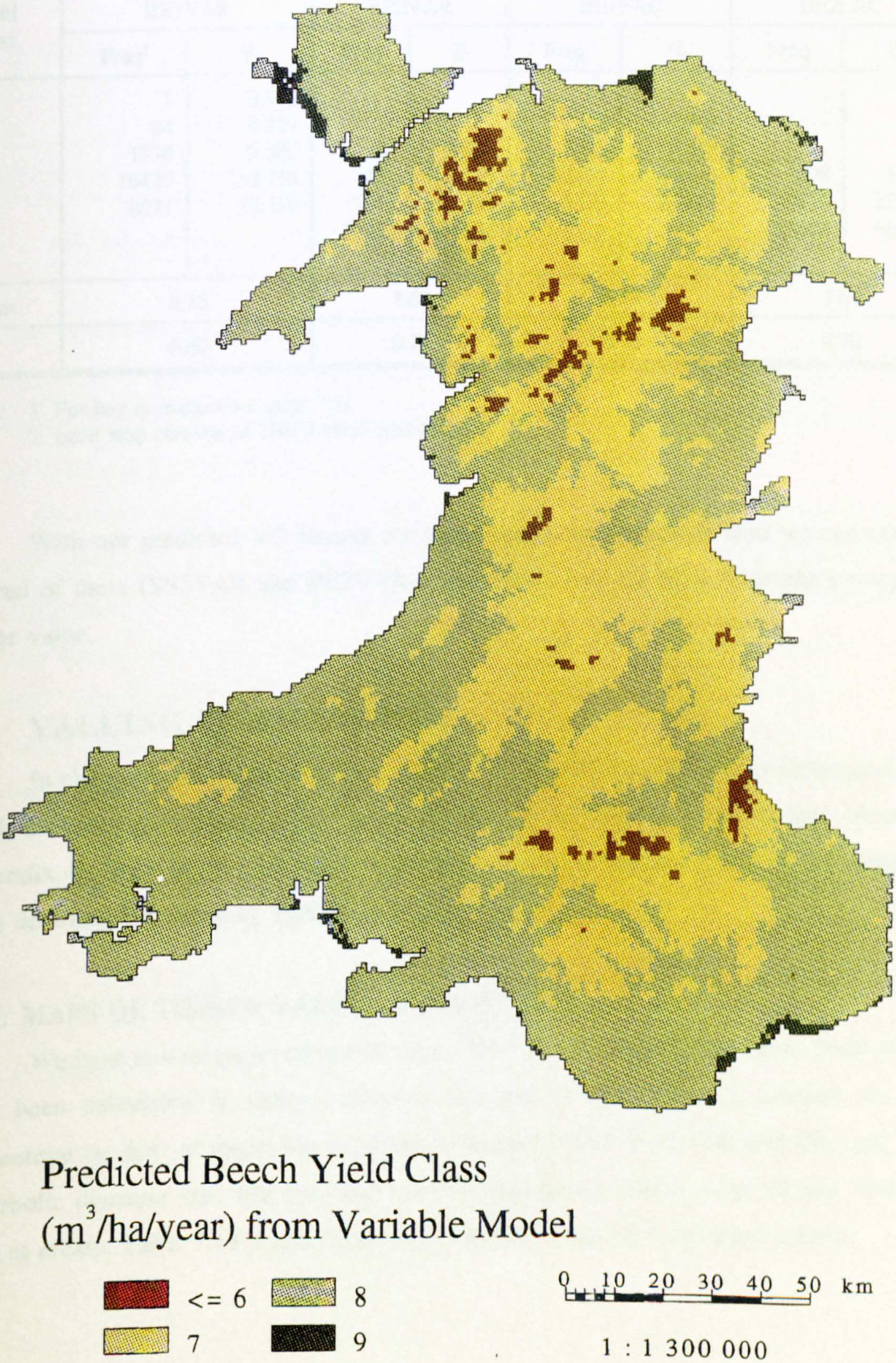

Table 7.13: Predicted timber yield class from various beech maps[1].

Yield Class	BE1VAR		BE2VAR		BE1FAC		BE2FAC	
	Freq[2]	%	Freq	%	Freq	%	Freq	%
3	1	0.005	-	-	-	-	-	-
4	84	0.409	-	-	14	0.068	-	-
5	1970	9.580	17	0.083	1725	8.389	-	-
6	10437	50.756	421	2.047	13251	64.440	208	1.012
7	8071	39.250	7003	34.056	5573	27.102	6775	32.948
8	-	-	12925	62.856	-	-	13580	66.041
9	-	-	197	0.958	-	-	-	-
Mean	6.25		7.69		6.19		7.63	
s.d.	0.80		0.78		0.76		0.70	

Notes: 1. For key to images see table 7.12
2. Each map consists of 20563 $1km^2$ land cells.

With our predicted YC images for Sitka spruce and beech defined we can take the optimal of these (SS3VAR and BE2VAR respectively) and use them to produce images of timber value.

7.7 VALUING TIMBER YIELD

In chapter 6 we produced tables of NPV and annuity equivalents for Sitka spruce and beech timber values across a full range of YC and at various discount rates (details in Appendix 4). We can now use those results to convert our optimal predicted YC images to maps detailing the monetary equivalent of those yields.

7.7.1: MAPS OF TIMBER VALUE: SITKA SPRUCE

We have two measures of timber value, NPV and its annuity equivalent. Each of these have been calculated at various discount rate and in the following analysis we shall concentrate on four of these: the exponential discount rates 1.5%, 3% and 6%; and a 6% hyperbolic discount rate. We therefore have 8 Sitka spruce timber value images which we wish to create. Table 7.14 details these and provides labels for subsequent referral.

Table 7.14: Sitka spruce GIS timber value images created: image labels

Value measure	Discount rate[1]			
	1.5%	3%	6%	6% hyperbolic
NPV	SS1tNPV	SS3tNPV	SS6tNPV	SS6HtNPV
Annuity	SS1tANN	SS3tANN	SS6tANN	SS6HtANN

Note: 1. All discount rates are exponential unless otherwise stated.

7.7.1.1: Estimating equations to convert from yield class to values

A simple method to relate the YC images to their value equivalents was to use the tables given in Appendix 4 as a source of data to estimate linear equations relating NPV and annuity values to YC for the various discount rates considered.

All timber values are considerably influenced by the planting grants and subsidy schemes applicable. As shown in chapter 6 there are a multitude of possible scenarios, planting grants and subsidy schemes under which trees might be planted. Consideration of all these permutations would make the following analysis impractically cumbersome and complex. Accordingly in the following we have taken the case which is most general for our study area, namely planting upon unimproved grassland without the benefit of Community Woodland Supplement. Deviations from the resulting financial measures can be calculated from the tables reported in chapter 6 and appendix 4.

Within this general case we have two rates of grant payable depending upon whether grants are paid at the rate for disadvantaged/specially disadvantaged areas (DA/SDA) or otherwise. Table 7.15 details linear equations linking Sitka spruce NPV sums for DA/SDA areas to YC across various discount rates while table 7.16 details results for an equivalent non-disadvantaged area.

Table 7.15: NPV of timber from an optimal rotation of Sitka spruce: linear predictive equations with YC as the single explanatory variable (various discount rates). For disadvantaged and severely disadvantaged areas.

Discount rate	Intercept (t-value)	Slope (t-value)	R^2 (adj)
1.5%	-3645.4 (-31.96)	996.621 (140.34)	100.0
3%	-3013.7 (-16.80)	570.20 (51.06)	99.7
6%	-1540.2 (-9.12)	209.02 (19.88)	97.8
6% hyperbolic	-2037.6 (-12.57)	558.78 (55.37)	99.7

Table 7.16: NPV of timber from an optimal rotation of Sitka spruce: linear predictive equations with YC as the single explanatory variable (various discount rates). For non-disadvantaged areas.

Discount rate	Intercept (t-value)	Slope (t-value)	R^2 (adj)
1.5%	-4204.9 (-36.88)	996.670 (140.39)	100.0
3%	-3540.9 (-19.74)	570.20 (51.07)	99.7
6%	-2008.0 (-11.89)	209.01 (19.87)	97.8
6% hyperbolic	-2518.6 (-15.53)	558.74 (55.34)	99.7

A similar analysis was also conducted to link Sitka spruce annuity values to YC estimates. Table 7.17 details linear equations linking Sitka spruce annuity equivalents for DA/SDA areas to YC across various discount rates, while table 7.18 details results for non-disadvantaged areas.

Table 7.17: Timber annuity equivalent of a perpetual series of optimal rotation of Sitka spruce: linear predictive equations with YC as the single explanatory variable (various discount rates). For disadvantaged and severely disadvantaged areas.

Discount rate	Intercept (t-value)	Slope (t-value)	R^2 (adj)
1.5%	-104.183 (-34.55)	25.3951 (135.28)	100.0
3%	-119.003 (-15.90)	21.4204 (45.97)	99.6
6%	-104.24 (-8.37)	13.8902 (17.91)	97.3
6% hyperbolic	-172.51 (-14.98)	44.0728 (61.45)	99.8

Table 7.18: Timber annuity equivalent of a perpetual series of optimal rotation of Sitka spruce: linear predictive equations with YC as the single explanatory variable (various discount rates). For non-disadvantaged areas.

Discount rate	Intercept (t-value)	Slope (t-value)	R^2 (adj)
1.5%	-116.398 (-38.55)	25.3135 (134.67)	100.0
3%	-136.324 (-17.88)	21.3151 (44.90)	99.6
6%	-132.22 (-10.67)	13.7573 (17.83)	97.2
6% hyperbolic	-207.35 (-17.74)	43.9472 (60.38)	99.8

7.7.1.2 Maps of timber NPV: Sitka spruce

Given that the majority of Wales qualifies for DA/SDA rates of subsidy we shall use these rates in the following images[32]. NPV maps for Sitka spruce timber value were produced by multiplying our optimal YC image (SS3VAR) by the relevant linear equation as detailed in table 7.15. This was achieved using the *Scalar* command discussed previously. This operation was repeated for each of the four discount rates considered to produce the images defined in the upper row of table 7.14. Table 7.19 details results from this analysis.

Table 7.19 clearly shows both the range of NPV sums which are implied by our YC predictions and the impact of varying discount rate upon these. As exponential discount rates increase so the absolute value of NPV, its range and consequently variance, decline markedly. Switching to hyperbolic discounting increases these measures of NPV substantially as shown.

Given our discussion of discount rates in chapter 6 we are less interested in the 6% exponential rate, including it mainly because this is the current relevant Treasury rate. Furthermore we recognise that the resistance which the economics profession has towards hyperbolic discounting makes such an approach unlikely to be given too much weight. Consequently we prefer to concentrate on out 1.5% and 3% rates and choose the latter to illustrate the distribution of NPV sums estimated by the above analysis as shown in figure 7.9.

The distribution of NPV sums shown in figure 7.9 strongly reflects that of the YC image upon which it is based (figure 7.6). Consequently our comments are as before.

7.7.1.3 Maps of timber annuity: Sitka spruce

Annuity equivalents of the NPV sums detailed in table 7.19 were prepared. This was again achieved via the Scalar command now relating our optimal Sitka spruce YC model (7.4) through the linear equations given in table 7.17 (DA/SDA areas), to produce the four annuity images described in the lower row of table 7.14. Results from this exercise are detailed in table 7.20.

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[32] An obvious extension, which we hope to address in future work, is to prepare a DA/SDA boundary image and use this to define a single map applicable to all areas of Wales. However, at the time of writing, permission to use such an image (which is Crown Copyright) had been requested but not granted.

Table 7.19: NPV sums for Sitka spruce timber GIS images at various discount rates (£/ha, 1990)

NPV (£/ha)	SS1tNPV		SS3tNPV		SS6tNPV		SS6HtNPV	
	Freq[1]	%	Freq	%	Freq	%	Freq	%
-500:-1	-	-	-	-	1	0.005	-	-
0:499	-	-	-	-	31	0.151	-	-
500:999	-	-	1	-	187	0.909	-	-
1000:1499	-	-	2	0.005	2232	10.854	-	-
1500:1999	-	-	8	0.010	5786	28.138	1	0.005
2000:2499	-	-	20	0.039	11208	54.506	4	0.019
2500:2999	-	-	24	0.097	1118	5.437	13	0.063
3000:3499	1	0.005	48	0.117	-	-	16	0.078
3500:3999	-	-	163	0.233	-	-	30	0.146
4000:4499	4	0.019	514	0.793	-	-	81	0.394
4500:4999	5	0.024	1019	2.500	-	-	239	1.162
5000:5499	10	0.048	1307	4.956	-	-	711	3.458
5500:5999	11	0.053	1757	6.356	-	-	1139	5.539
6000:6499	8	0.039	2556	8.544	-	-	1480	7.197
6500:7000	17	0.083	3380	12.430	-	-	2073	10.081
7000:7499	23	0.112	4055	16.437	-	-	2927	14.234
7500:7999	62	0.302	4534	19.720	-	-	3919	19.059
8000:8499	80	0.389	1173	22.049	-	-	4447	21.626
8500:8999	207	1.007	2	5.704	-	-	3358	16.330
9000:9499	352	1.712	-	0.010	-	-	125	0.608
9500:9999	525	2.553	-	-	-	-	-	-
10000:10499	649	3.156	-	-	-	-	-	-
10500:10999	739	3.594	-	-	-	-	-	-
11000:11499	826	4.017	-	-	-	-	-	-
11500:11999	1112	5.408	-	-	-	-	-	-
12000:12499	1194	5.807	-	-	-	-	-	-
12500:12999	1595	7.757	-	-	-	-	-	-
13000:13499	1820	8.851	-	-	-	-	-	-
13500:13999	2162	10.514	-	-	-	-	-	-
14000:14499	2225	10.820	-	-	-	-	-	-
14500:15000	2605	12.668	-	-	-	-	-	-
15000:15499	2600	12.644	-	-	-	-	-	-
15500:15999	1561	7.591	-	-	-	-	-	-
16000:16499	168	0.817	-	-	-	-	-	-
16500:16999	2	0.010	-	-	-	-	-	-
Mean	13362.45		6707.30		2023.25		7488.72	
s.d.	1938.29		1189.19		438.32[2]		1167.57	

Notes: 1. From a total of 20563 $1km^2$ land cells.
2. Estimated (not calculated due to the GIS assigning zero values to non-land cells; this problem is adjusted for in the calculation of the mean).

Figure 7.9: Image SS3tNPV: predicted timber NPV sums for Sitka spruce (based on yield class image SS3VAR; optimal no-factor model 7.4). Discount rate = 3% (£/ha, 1990)

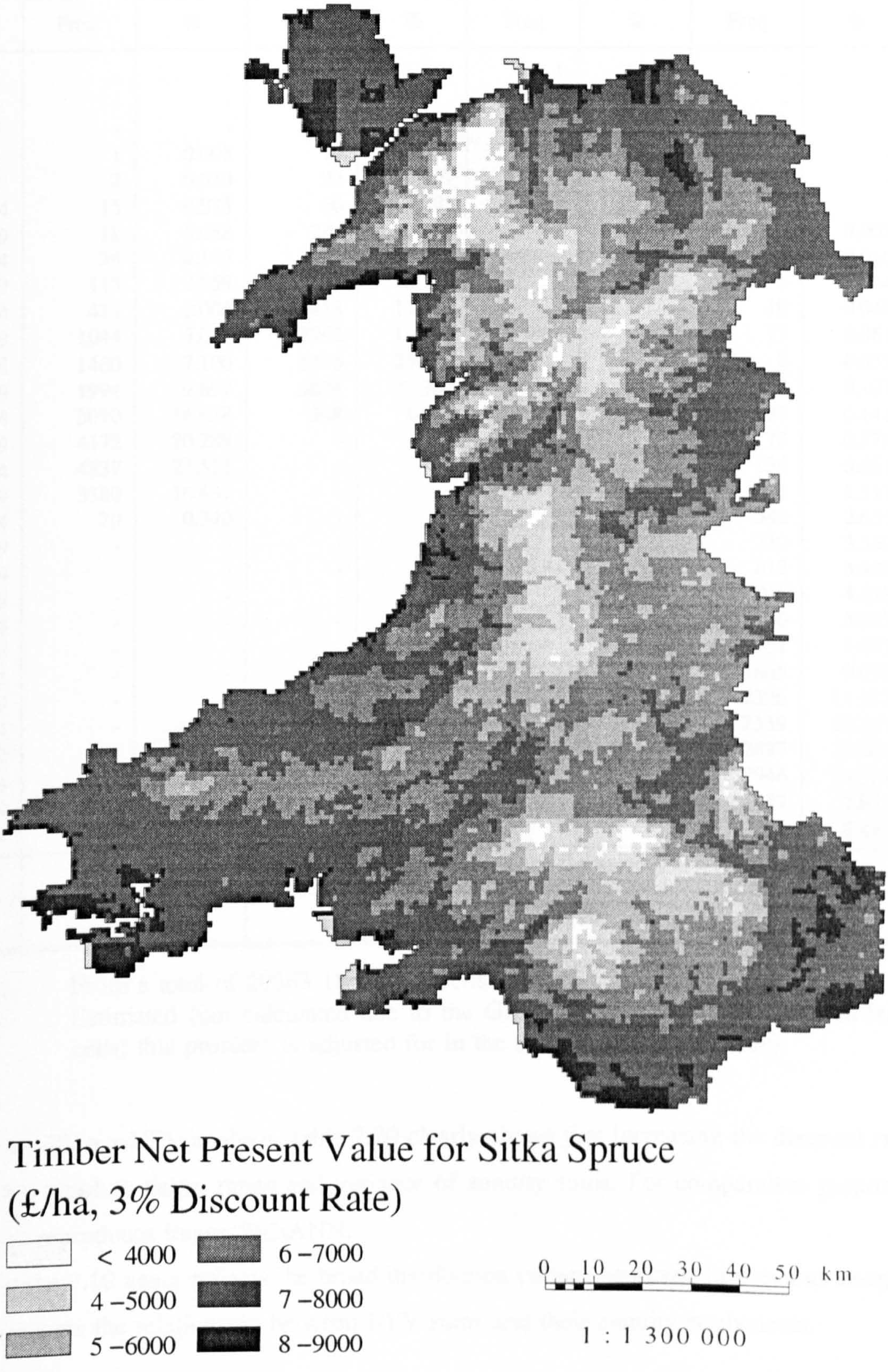


Table 7.20: Annuity values for Sitka spruce timber at various discount rates (£/ha, 1990)

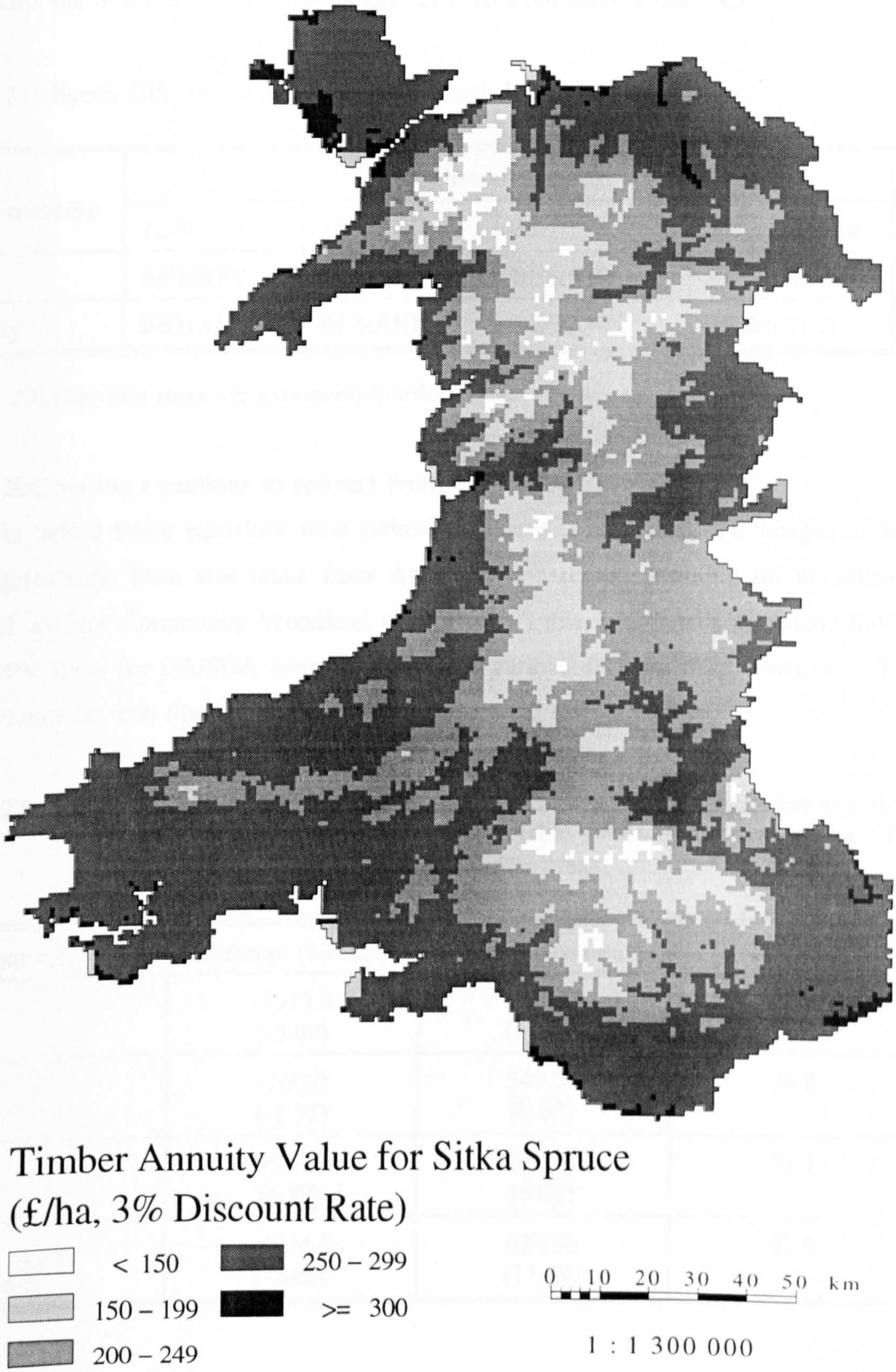
Annuity value (£/ha)	SS1tANN		SS3tANN		SS6tANN		SS6HtANN	
	Freq[1]	%	Freq	%	Freq	%	Freq	%
-25:-1	-	-	-	-	1	0.005	-	-
0:24	-	-	-	-	21	0.102	-	-
25:49	-	-	3	0.015	53	0.258	-	-
50:74	1	0.005	16	0.079	479	2.329	-	-
75:99	2	0.010	22	0.107	2183	10.616	-	-
100:124	15	0.073	60	0.292	4068	19.783	-	-
125:149	18	0.088	263	1.279	7318	35.588	1	0.005
150:174	34	0.165	993	4.829	6434	31.289	2	0.010
175:199	115	0.559	1682	8.180	6	0.029	5	0.024
200:224	411	2.000	2413	11.735	-	-	10	0.048
225:249	1044	5.077	3962	19.268	-	-	13	0.063
250:274	1460	7.100	5175	25.167	-	-	8	0.039
275:299	1994	9.697	5626	27.360	-	-	22	0.107
300:324	3010	14.638	348	1.692	-	-	29	0.141
325:349	4172	20.289	-	-	-	-	78	0.379
350:374	4837	23.523	-	-	-	-	136	0.661
375:399	3380	16.437	-	-	-	-	312	1.517
400:424	70	0.340	-	-	-	-	546	2.655
425:449	-	-	-	-	-	-	730	3.550
450:474	-	-	-	-	-	-	812	3.949
475:499	-	-	-	-	-	-	966	4.698
500:524	-	-	-	-	-	-	1230	5.982
525:549	-	-	-	-	-	-	1551	7.543
550:574	-	-	-	-	-	-	1865	9.070
575:599	-	-	-	-	-	-	2326	11.312
600:624	-	-	-	-	-	-	2539	12.347
625:649	-	-	-	-	-	-	2897	14.088
650:674	-	-	-	-	-	-	2946	14.327
675:699	-	-	-	-	-	-	1447	7.037
700:724	-	-	-	-	-	-	92	0.447
Mean	328.84		246.18		132.57		578.86	
s.d.	54.17		47.61		30.10[2]		86.44	

Notes: 1. From a total of 20563 $1km^2$ land cells.
2. Estimated (not calculated due to the GIS assigning zero values to non-land cells; this problem is adjusted for in the calculation of the mean).

As with our NPV analysis, table 7.20 clearly shows that increasing the discount rate reduces the absolute value, range and variance of annuity sums. For comparative purposes figure 7.10 reproduces image SS3tANN.

Figure 7.10 again reflects the broad distribution pattern observed in previous images and underscores the relationship between NPV sums and their annuity equivalents.

Figure 7.10: Image SS3tANN: predicted timber annuity equivalents for Sitka spruce (based on yield class image SS3VAR; optimal no-factor model 7.4). Discount rate = 3% (£/ha, 1990)



7.7.2 MAPS OF TIMBER VALUE: BEECH

As before we calculate NPV and annuity equivalents for our four discount rates. Table 7.21 details the 8 beech timber value images created from such an analysis.

Table 7.21: Beech GIS timber value images created: image labels.

Value measure	Discount rate[1]			
	1.5%	3%	6%	6% hyperbolic
NPV	BE1tNPV	BE3tNPV	BE6tNPV	BE6HtNPV
Annuity	BE1tANN	BE3tANN	BE6tANN	BE6HtANN

Note: 1. All discount rates are exponential unless otherwise stated.

7.7.2.1: Estimating equations to convert from yield class to values

As before linear equations were estimated to related our Beech YC images to their value equivalents. Data was taken from Appendix 4 assuming planting on unimproved grassland without Community Woodland supplement. Table 7.22 details equations linking beech NPV sums for DA/SDA areas to YC across various discount rates while table 7.23 reports results for non-disadvantaged areas.

Table 7.22: NPV of timber from an optimal rotation of beech: linear predictive equations with YC as the single explanatory variable (various discount rates). For disadvantaged and severely disadvantaged areas.

Discount rate	Intercept (t-value)	Slope (t-value)	R^2 (adj)
1.5%	-1513.9 (-3.09)	749.95 (11.26)	97.7
3%	-260.0 (-1.35)	349.50 (9.63)	96.8
6%	455.90 (5.89)	63.30 (6.01)	92.1
6% hyperbolic	-1024.8 (-2.65)	624.90 (11.89)	97.9

Table 7.23: NPV of timber from an optimal rotation of beech: linear predictive equations with YC as the single explanatory variable (various discount rates). For non-disadvantaged areas.

Discount rate	Intercept (t-value)	Slope (t-value)	R^2 (adj)
1.5%	-2299.9 (-4.70)	749.95 (11.26)	97.7
3%	-1096.7 (-4.10)	349.35 (9.60)	96.8
6%	-160.20 (-2.07)	63.10 (5.98)	92.1
6% hyperbolic	-1679.4 (-4.36)	624.70 (11.92)	97.9

A similar analysis was also conducted to link beech annuity values to YC estimates. Table 7.24 details linear equations linking annuities to YC across various discount rates for DA/SDA areas, while table 7.25 details results for non-disadvantaged areas.

Table 7.24: Timber annuity equivalent of a perpetual series of optimal rotation of beech: linear predictive equations with YC as the single explanatory variable (various discount rates). For disadvantaged and severely disadvantaged areas.

Discount rate	Intercept (t-value)	Slope (t-value)	R^2 (adj)
1.5%	-29.832 (-3.20)	14.416 (11.36)	97.7
3%	-12.813 (-1.48)	11.327 (9.64)	96.8
6%	27.032 (5.63)	4.009 (6.13)	92.4
6% hyperbolic	-76.02 (-2.76)	44.553 (11.88)	97.9

Table 7.25: Timber annuity equivalent of a perpetual series of optimal rotation of beech: linear predictive equations with YC as the single explanatory variable (various discount rates). For non-disadvantaged areas.

Discount rate	Intercept (t-value)	Slope (t-value)	R^2 (adj)
1.5%	-44.445 (-4.73)	14.373 (11.23)	97.7
3%	-35.687 (-4.10)	11.246 (9.50)	96.7
6%	-10.143 (-2.10)	3.9165 (5.97)	92.0
6% hyperbolic	-121.30 (-4.36)	44.444 (11.74)	97.9

7.7.2.2 Maps of timber NPV: beech

As before we assume DA/SDA rates for the following analysis. NPV images were produced as per our Sitka spruce analysis. Table 7.26 details results for the four beech timber NPV images defined in the upper row of table 7.21.

Table 7.26: NPV sums for beech timber GIS images at various discount rates (£/ha, 1990)

NPV (£/ha)	BE1tNPV		BE3tNPV		BE6tNPV		BE6HtNPV	
	Freq[1]	%	Freq	%	Freq	%	Freq	%
500: 999	-	-	-	-	20563	100.000	-	-
1000:1499	-	-	10	0.049	-	-	-	-
1500:1999	-	-	1281	6.229	-	-	-	-
2000:2499	10	0.049	14524	70.626	-	-	27	0.131
2500:2999	97	0.472	4748	23.088	-	-	332	1.615
3000:3999	5410	26.307	-	-	-	-	13440	65.355
4000:4999	15046	73.165	-	-	-	-	6764	32.891
mean	4250.78		2326.53		942.49		3778.66	
s.d.	494.83		331.31		317.49		426.95	

Notes: 1. From a total of 20563 1km² land cells.

Analysis of table 7.26 shows a similar pattern of NPV to those observed for Sitka spruce. However, as a result of the longer delay in returns and their lower growth rate, the absolute level of timber NPVs for beech are considerably below those observed for Sitka spruce. To allow comparison with the SS3tNPV image printed above (figure 7.9), figure 7.11. reproduces image BE3tNPV.

Figure 7.11 shows the now familiar pattern of values corresponding closely to the environmental characteristics of sites. Comments are therefore as before.

7.7.2.3 Maps of timber annuity: beech

Annuity equivalents were prepared as before. Results for all four of the images defined in the lower row of table 7.26 are given in table 7.32.

Table 7.27: Annuity equivalents for beech timber GIS images various discount rates (£/ha, 1990)

Annuity (£/ha)	BE1tANN		BE3tANN		BE6tANN		BE6HtANN	
	Freq[1]	%	Freq	%	Freq	%	Freq	%
40:49	20	0.097	20	0.097	37	0.180	-	-
50:59	179	0.870	327	1.590	16203	78.797	-	-
60:69	1798	8.744	4756	23.129	4323	21.023	-	-
70:79	6253	30.409	10841	52.721	-	-	-	-
80:89	8960	43.573	4619	22.463	-	-	-	-
90:99	3353	16.306	-	-	-	-	-	-
100:149	-	-	-	-	-	-	1	0.005
150:199	-	-	-	-	-	-	173	0.841
200:249	-	-	-	-	-	-	4962	24.131
250:310	-	-	-	-	-	-	15427	75.023
mean	80.98		74.25		57.85		266.45	
s.d.	12.97		12.09		11.52		26.97	

Notes: 1. From a total of 20563 $1km^2$ land cells.

For comparative purposes, figure 7.12 reproduces image BE3tANN. The shows clearly the expected pattern of values. Other comments are as before.

Figure 7.11: Image BE3tNPV: predicted timber NPV sums for beech (based on yield class image BE2VAR; optimal no-factor model 7.8). Discount rate = 3% (£/ha, 1990)

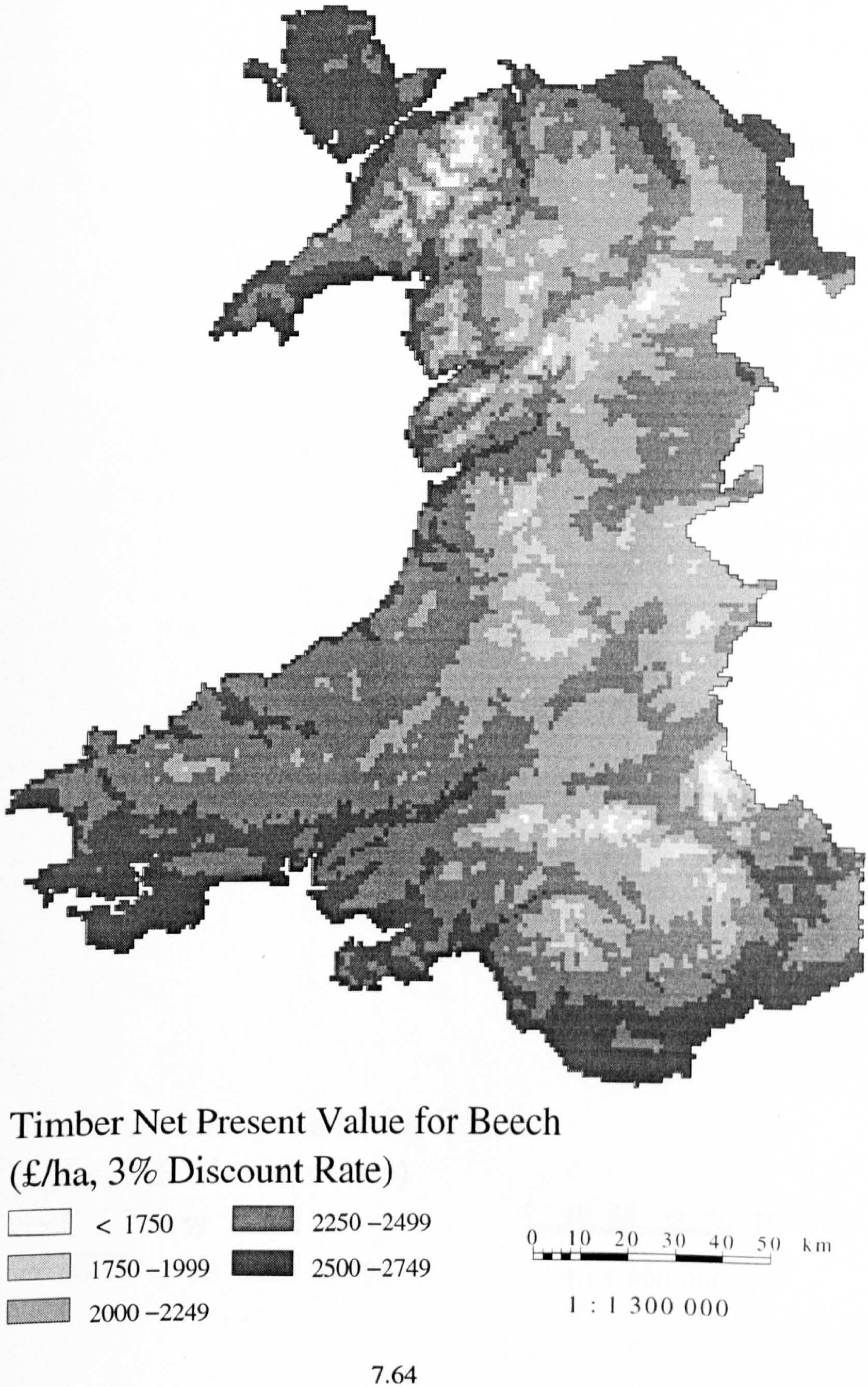
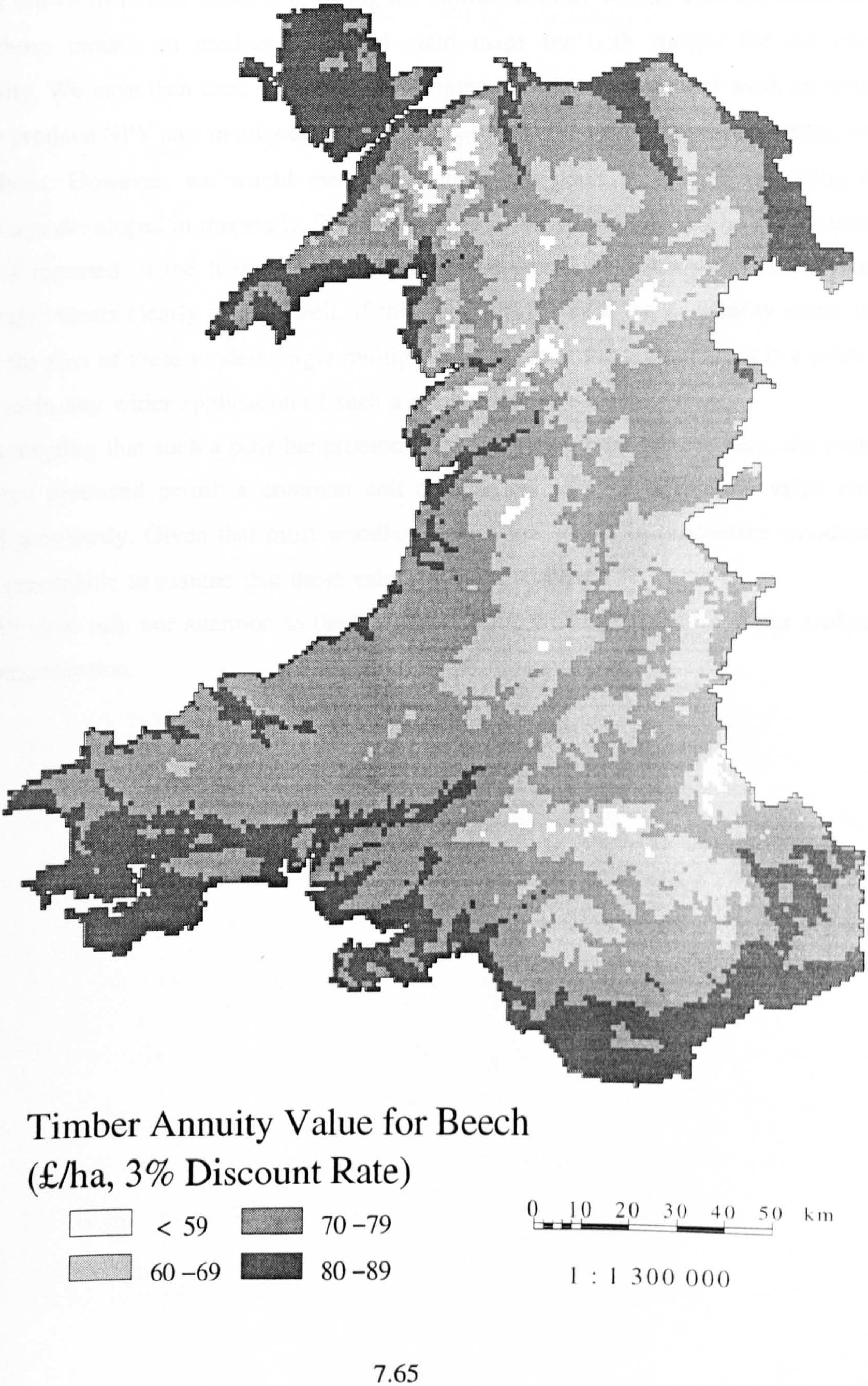


Figure 7.12: Image BE3tANN: predicted timber annuity values for beech (based on yield class image BE2VAR; optimal no-factor model 7.8). Discount rate = 3% (£/ha, 1990)



7.8 CONCLUSIONS

We have estimated yield class models for Sitka spruce and beech based in part upon variables drawn from GIS datasets covering the entire extent of Wales. This has allowed us to use those models to produce predicted yield maps for both species for the entire Principality. We have then used these maps in conjunction with our previous work on timber values to produce NPV and annuity equivalent maps. In general we are reasonably happy with this analysis. However, we would mention at least one point of caution regarding the methodology developed in this study. The YC models fit the data quite well by the standards of models reported in the literature. Furthermore, the equations linking YC to NPV and annuity equivalents clearly also fit well. If this were not the case the possibility exists that errors in the first of these models might multiply with those at the second. This is a point to be wary of in any wider application of such a methodology.

Accepting that such a possible problem does not seem to be present here, the timber value maps produced permit a common unit comparison with the recreation value maps produced previously. Given that most woodland recreation occurs in productive woodlands it seems reasonable to assume that these values may be additive.

We now turn our attention to the last forest value we shall consider in our analysis: carbon sequestration.

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Chapter 8: Modelling and Valuing Carbon Sequestration in Trees, Timber Products and Forest Soils

8.1 INTRODUCTION

The global process of industrialisation which has grown so rapidly over the past two centuries has, in more recent years, led to detectable increases in the concentration of insulating greenhouse gases (GHGs). These have coincided with elevations in global temperatures which are expected to continue rising with GHG emissions for the foreseeable future. Best estimates suggest that global surface air temperature will rise by more than 1°C between 1990 and 2050 and by 2°C in less than a century from the present day (Houghton *et al.*, 1992; Wigley and Raper, 1992)[1]. The consequences of such climatic change are uncertain but potentially highly adverse (Parry 1993; Warr and Smith 1993).

The advent of the global warming debate has raised interest in the potential for using forestry as a way of reducing atmospheric concentrations of carbon dioxide (Sedjo, 1989; Myers, 1990; Nordhaus, 1991a), the gas which in absolute terms provides the largest contribution to global insulation[2]. In effect such papers add a new category to the timber, recreation and other traditional benefits of woodland; namely carbon sequestration. However, assessment of this benefit is not straightforward.

An initial and daunting problem concerns the valuation of sequestered carbon. This has been a subject of heated debate within the economics literature. A number of articles have been heavily criticised for failing to grasp the complexity of climatic processes which underlie global warming. We review the literature in some detail in Appendix 6 and defend our use of the recent valuation work of Sam Fankhauser as being both more sophisticated and based upon significantly more realistic climate change models than preceding work. A brief review of the debate is presented at the start of Section 8.2.

Our review of literature also considers the physical processes of carbon sequestration in trees and forest soils, carbon storage within timber products, and eventual liberation back

[1]The global warming literature is reviewed in some detail in Appendix 6.1

[2]It should be stressed that this can only be a marginal stopgap measure providing temporary relief in the wake of necessary reductions in emissions. As Nowak (1993) emphasises, planting 10 million trees per annum for the next 50 years will sequester less then 1% of US emissions during that period.

to the atmosphere, for carbon storage within trees is only a transitory process and total storage can only grow while the volume of timber increases. Nevertheless the potential for expanding forest areas (heightened in the EC by surpluses of agricultural land) means that forests do provide a vital breathing space before policy and technological change can address the root cause of global warming[3].

Section 8.3 presents a brief overview of our research methodology. This is applied in Section 8.4 to the modelling of carbon flux in both Sitka spruce trees and their products, while Section 8.5 extends this analysis to beech. The impacts of afforestation upon soil carbon levels are considered in Section 8.6, while Section 8.7 presents results from the above analyses. Finally, Section 8.8 applies GIS techniques to the production of carbon sequestration potential maps and corresponding evaluation maps.

8.2 LITERATURE REVIEW

This section opens by considering the ongoing debate concerning the valuation of carbon emissions and their storage. The section then moves to consider three aspects of carbon sequestration via afforestation: the storage of carbon in trees; its post-felling liberation; and the impact of afforestation upon soil carbon flux.

8.2.1 THE SHADOW PRICE OF CARBON EMISSIONS

While a number of studies have examined the costs of fixing carbon via afforestation relatively few have attempted to quantify its benefits. For our purposes the most interesting of these are those adopting a damage-avoided approach to valuation. If accurate, estimates produced by such methods are shadow prices which may be directly incorporated within the cost-benefit framework which underpins our wider study.

The pioneering work on the shadow price of CO_2 emissions is that of Nordhaus (1991b,c). Using a very simple model and assuming a 3% discount rate he calculates social costs of $7.3/tonne of C emitted. These estimates provoked a number of critical responses

[3]Alternatively, in the absence of such policy change (which seems quite possible), forestry extends the period of grace which the human race may enjoy before the full consequences of global warming hit home! Afforestation cannot provide the degree of carbon sequestration necessary to be an alternative to policy change.

(Ayres and Walter, 1991;[4] Daily *et al.*, 1991; Grubb, 1992) the most perceptive of which (Cline, 1992a) highlights the simple linear structure of the underlying model implying both a constant level of CO_2 emissions[5] and constant shadow price through time.

In subsequent work Nordhaus (1992a,b) addresses many of these criticisms. His Dynamic Integrated Climate Economy (DICE) model uses optimal economic growth analysis in combination with a climate model which feeds climate changes back into the economy as damages. The resulting carbon shadow prices are similar to his earlier estimates ($5.3/tC in 1995 rising to $10/tC in 2025). However, Nordhaus' results have again been criticised by Cline (1992b) who suggests that the parameter values used result in an underestimation of true costs.

A similar model, utilizing a more detailed economy component, is used by Peck and Teisberg (1992a,b). Their 'Carbon Emission Trajectory Assessment' (CETA) model produces estimates of the shadow price of carbon ranging from $10/tC in 1990 to $22/tC in 2030. Given that the CETA model is structurally similar to DICE, the main reason explaining differences in the shadow price estimates produced appears to be discrepancies in assumptions regarding carbon damages.

Important recent contributions to the shadow pricing debate are provided by the papers of Fankhauser (1993a,b, 1994a,b, 1995). These introduce a fully stochastic, greenhouse damages model, explicitly recognising the highly non-linear and uncertain aspects of the climate process. Uncertainty is incorporated by modelling all key parameters as random variables[6]. The model consists of modules examining: future emissions; atmospheric concentration; radiative forcing; temperature rise; annual damage; costs of sea-level rise protection; and discounting.

[4]It is somewhat ironic that Ayres and Walter criticise the Nordhaus (1991b,c) estimates as too low given that in an earlier paper they assess emissions damage costs at between $5-10/ton CO_2 ($18-37/tC) (Walter and Ayres, 1990). In their subsequent critique of Nordhaus they apply different assumptions to his model to produce a damage estimate of $30-35/tonne C (Ayres and Walter, 1991). However, given the problems of the simple linear Nordhaus model, such estimates must be treated with extreme caution (Fankhauser, 1993b, shows that, in addition to the simplicity of the first Nordhaus model, it also contains a mathematical error).

[5]Annual CO_2 emissions are predicted to rise from 7.4 GtC in 1990 to 9-14 GtC by 2025 (IPCC, 1992). Climate processes are clearly not first-order linear.

[6]Here triangular distributions (using upper/lower bounds and the best guess estimate) are generally assumed although where upper and lower bounds were unknown a modest range of 10% around the best guess was used. These assumptions are the subject of ongoing research by Fankhauser.

Fankhauser (1994b) addresses the discounting problem in a more detailed manner than other shadow pricing assessment of carbon. Considering the literature on the subject, he sets the pure rate of time preference (ρ) as a random variable with upper and lower bounds of 3% and 0% respectively and with a best guess (mode) value of 0.5%. Similarly the income elasticity of utility (ω) is defined as a random variable with upper and lower bounds of 0.5 and 1.5 respectively and a best guess (mode) value of 1. This random variable discounting captures the uncertainty regarding these parameters. Furthermore, if we recall our discussion of discounting in Chapter 6, the low discount rate resulting from such a choice of parameter values seems much more defensible as a reflection of social preference regarding the assessment of global warming impacts, than does the comparatively high 3% rate used in the other studies reviewed above. However, to allow comparability with these other studies Fankhauser also conducts a conventional discounting sensitivity analysis using values of ρ = 0 and 0.03 with ω = 1 throughout.

The Fankhauser (1994b) model differs therefore from its predecessors in at least three important aspects:

(i) it models climate feedback mechanisms in a more detailed and realistic manner;
(ii) it uses expected (means) rather than best guess (mode) values;
(iii) it employs a discount rate sensitivity analysis.

Table 8.1 contrasts results from Fankhauser's (1994b) random variable discounting model of CO_2 damage costs with those discussed previously. For the latter only a best guess (mode) value is reported while, emphasising the importance of damage distributions, Fankhauser reports expected (mean) values as well as 5% and 95% percentiles, standard deviation and skewedness. Given factors (i) to (iii) above, the discrepancy between Fankhauser's results and those of other studies[7] are to be expected.

[7]Ignoring Ayres and Walter (1991) for reasons given previously.

Table 8.1: The social costs of CO_2 emissions ($/tC): comparison across studies

Study	Measure	1991-2000	2001-2010	2011-2020	2021-2030
Nordhaus[1] (1991a,b)	Best guess (mode)	7.3 (0.3-65.9)			
Ayres and Walter[1] (1991)	Best guess (mode)	30-35			
Nordhaus[1] (1992a)	Best guess (mode)	5.3	6.8	8.6[2]	10.0
Peck and Teisberg[1] (1992b)	Best guess (mode)	10-12[2]	12-14[2]	14-18[2]	18-22[2] (3.4-57.6)
Fankhauser (1994b)[3]	Expected (mean) 5th percentile 95th percentile standard dev. skewedness	20.3 6.2 45.2 14.3 2.5	22.8 7.4 52.9 16.0 2.5	25.3 8.3 58.4 17.5 2.5	27.8 9.2 64.2 19.0 2.4

Notes: Figures in brackets denote confidence intervals.
[1] Discount rate = 3% for all studies except Fankhauser (1994b).
[2] Figures measured from graph as reported in Fankhauser (1993b).
[3] Random variable discounting: ρ = (0, 0.005, 0.03); ω =(0.5, 1, 1.5).

Results from Fankhauser's discount rate sensitivity analysis are given for two time periods in Table 8.2. As can be seen, using a common time preference rate of 3% the estimates of Fankhauser (1994b) and Nordhaus (1992a) are quite comparable. Arguably this could be taken as evidence that differences (i) and (ii) above are not particularly significant. However, more surely it reflects the fact that the choice of discount rate in calculating damage estimates is of prime importance. Global warming is a very long term issue and discounting effects are consequently large. Given this, the assumptions underpinning Fankhauser's approach seem more defensible.

Table 8.2: The social costs of CO_2 emissions ($/tC): discount rate sensitivity analysis

Discounting assumption	Statistic	Value ($/tC)	
		1991-2000	2021-2030
Random case ρ = (0, 0.005, 0.03) ω = (0.5, 1, 1.5)	mean ($/tC) 5th percentile 95th percentile standard dev. skewedness	20.3 6.2 45.2 14.3 2.5	27.8 9.2 64.2 19.0 2.4
Low discounting $\rho = 0$ $\omega = 1$	mean ($/tC) 5th percentile 95th percentile standard dev. skewedness	48.8 27.6 80.1 15.6 0.9	62.9 34.9 104.6 22.4 1.3
High discounting $\rho = 0.03$ $\omega = 1$	mean ($/tC) 5th percentile 95th percentile standard dev. skewedness	5.5 3.7 7.6 1.2 0.5	8.3 5.3 12.0 2.1 0.8

Source: Fankhauser (1994b)

In conclusion, the debate regarding the valuation of carbon emissions is still in its early years and very much ongoing[8]. Nevertheless the physical science underpinning economic models and the sophistication of ensuing analysis has progressed markedly in recent years. The work of Fankhauser appears to be on the cutting edge in both of these respects and we feel that estimates from his model provide the firmest contemporary basis for our wider valuation work.

8.2.2 CARBON STORAGE IN TREES[9]

8.2.2.1 Calculating carbon storage

Roughly 50% of the woody biomass of a tree is carbon, therefore growing new trees fixes carbon over the lifetime of those trees. The quantity of carbon stored by a particular tree can be calculated as follows[10]:

[8]See our discussion of equity issues in Appendix 6.1.

[9]Sedjo et al., (1995) review the literature concerning the economics of storing carbon in trees.

[10]The following description draws upon conversations during 1994 and 1995 with Robert Matthews, mensuration officer at the Forestry Commission's Research Station, Alice Holt Lodge, Surrey.

i) The Forestry Commission produces yield models (Edwards and Christie 1981) quantifying cumulative timber production (in m^3/ha) adjusted for:

   a) species;
   b) growth rate (measured as YC);
   c) spacing of trees;
   d) thinning regime.

   These models record the merchantable volume of timber per hectare at varying ages from planting.

ii) Merchantable volume is defined as "Vol/ha: the overbark volume, in cubic metres per hectare, of the live trees. In conifers, all timber on the main stem which has an overbark diameter of at least 7 cm is included. In broadleaves, the measurement limit is either to 7 cm, or to the point at which no main stem is distinguishable, whichever comes first" (Edwards and Christie, 1981). This definition means that merchantable volume may be significantly less than overall woody volume (which is more relevant for the assessment of carbon storage), particularly in young trees. Consequently the merchantable volume estimate needs to be inflated by the ratio of total woody volume to merchantable volume[11]. This ratio will initially be very high (technically ∞) and fall rapidly as the tree grows until an asymptotic equilibrium is attained. Figure 8.1 illustrates an example of such a multiplier for Sitka spruce (YC12). Broadleaved species such as beech will have, at all ages, higher ratio values declining to an asymptotic equilibrium of about 1.8-2.0.

iii) The total woody volume can now be related to the corresponding oven dry biomass level (the dry weight; DW) by reference to the density (nominal specific gravity; SG) of the wood. SG is generally higher in broadleaves than conifers. Adger and Brown (1994) report SG = 0.34 for Sitka spruce and SG = 0.60 for beech.

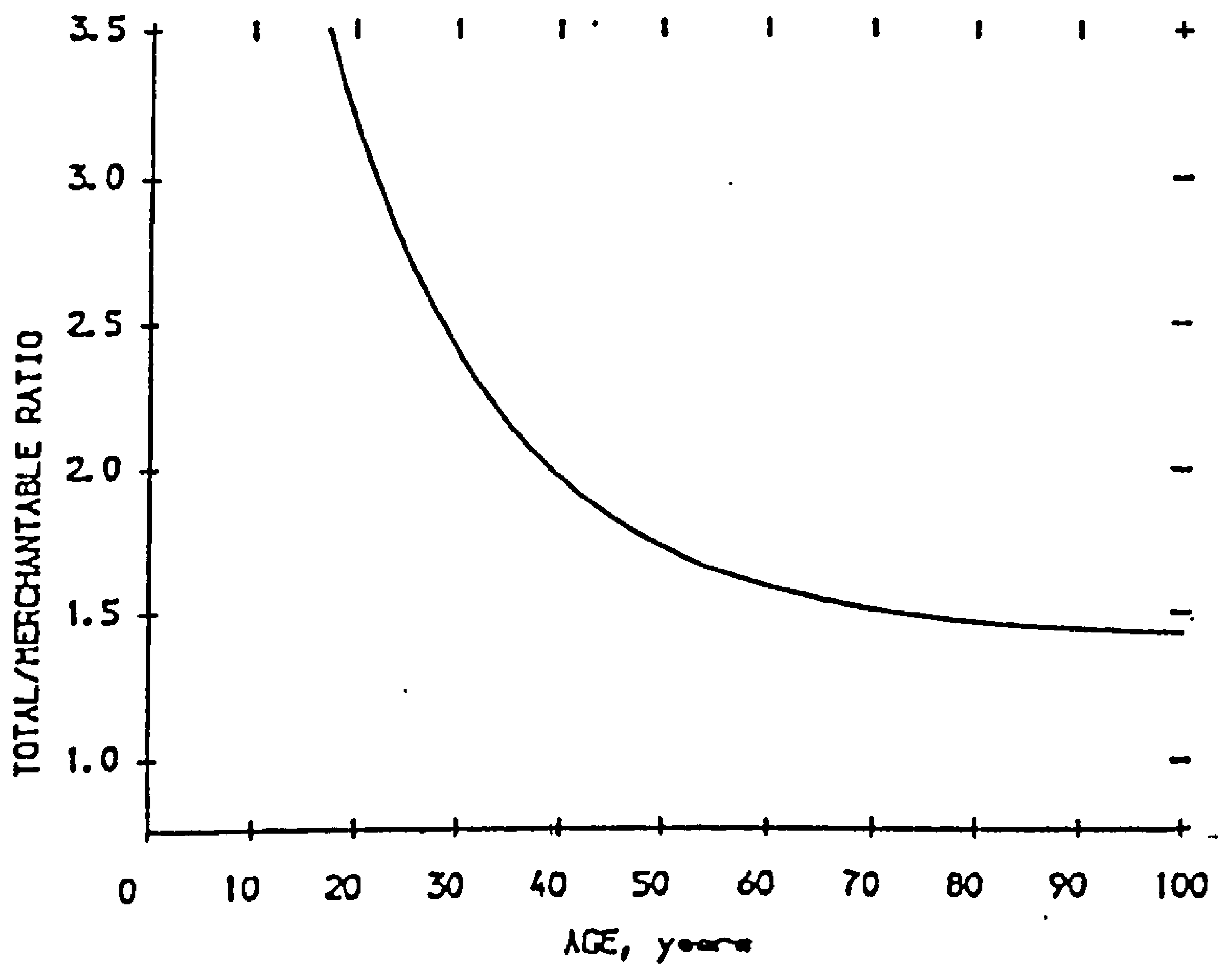
iv) Thompson and Matthews (1989a) note that variance in the "proportions of cellulose, hemicelluloses and lignin" (*ibid*) between differing species leads to differences in the proportion of biomass which is carbon. However, Matthews (1993)[12] reports figures of just over 49% for both Sitka spruce and beech.

---

[11]Corbyn, Crockford and Savill (1988) give details regarding the branchwood component of total tree volume.

[12]Note that this reference refers to the paper by George Matthews (1993), all subsequent references to Matthews (1993) refer to the paper by Robert Matthews.

Figure 8.1: Change in ratio of total/merchantable volume with age for YC12 Sitka spruce (2 m spacing, intermediate thinning).



Source: Matthews (1991)

Calculating tree carbon storage: example

40-year old YC12 Sitka spruce, 2 m spacing, intermediate thinning

Merchantable volume (cumulative production in year 40) = 399 m^3/ha

Total/merchantable volume ratio @ 40 years = 2.0

$\therefore$ Total woody volume = 798 m^3/ha

Nominal specific gravity = 0.33

$\therefore$ Total biomass = 263 m^3

Total carbon = 0.42 * biomass = 110 tC/ha

The above example is based upon the cumulative merchantable volume for year 40. This includes both the maincrop (after thinning) for that year and all thinnings to date (in years 25, 30, 35 and 40). This approach is different to the early work of Matthews (1991) who ignores all thinnings and uses a constant total/merchantable ratio of 1.5 for all years[13]. Using such assumptions reduces estimated carbon fixing to 57 tC/ha at year 40.

[13]Note that the estimates reported in Pearce (1991) draw on this early work.

Because of uncertainties surrounding the total/merchantable volume curve (such a curve has not to date been published for broadleaves) rather than attempt to calculate carbon storage at different points over the rotation, we rely principally upon the work of Matthews (1993) with respect to conifers and Dewar and Cannell (1992) with respect to broadleaves. These have distinct advantages over earlier references in that they supply at least some information regarding the shape of carbon storage functions and incorporate up-to-date knowledge regarding sequestration in trees. Nevertheless a considerable amount of analysis was necessary in order to produce models which predicted across YC (the above references hold this factor constant) and provide the necessary information for economic analysis. In order to construct such a flexible model we need to first consider the variety of factors which affect the storage of carbon within living wood.

8.2.2.2 Factors affecting tree carbon storage

Physical factors affecting tree carbon storage are as follows:

(i) yield class and related factors
(ii) species
(iii) management regime

These factors are now considered in turn.

(i) Yield class and related factors

Tree carbon storage is directly related to growth rate and so increases over time from planting as per the S-shaped YC curves illustrated in Chapter 7 which also discusses the specific determinants of YC. Cannell and Cape (1991) produce YC/carbon storage curves for Sitka spruce as illustrated in Figure 8.2.

Studying Figure 8.2 we can see that, while the volume growth curve is sigmoidal, there is a roughly straight line relationship between YC and mean annual increment (MAI) of carbon sequestration[14].

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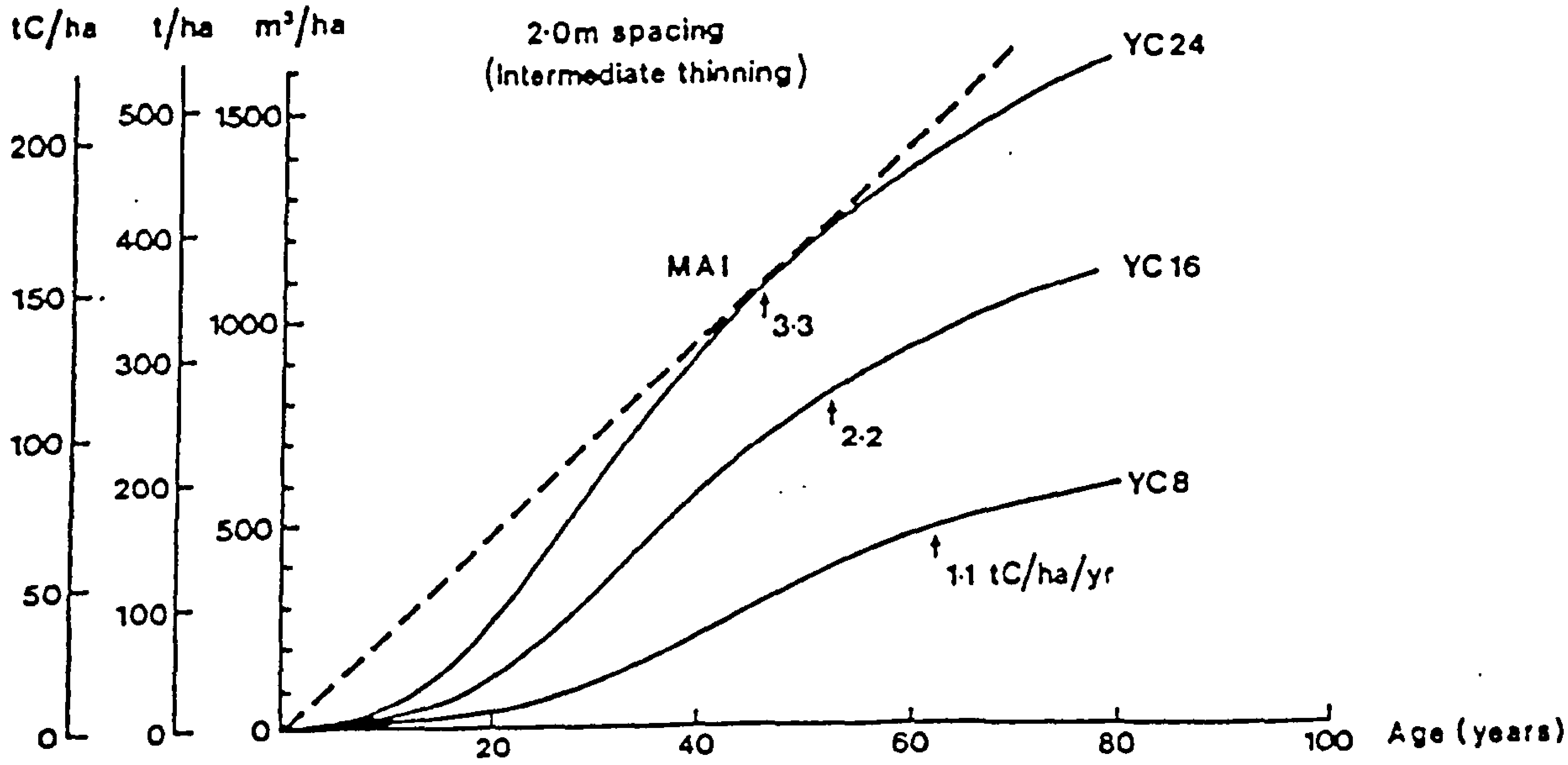
[14]Conversations with Donald Thompson (1993), Principal Silviculturalist at the Forestry Commission's Alice Holt Lodge research station, confirmed that such a straight line relationship is acceptable.

Figure 8.2: Volume (M^3/ha), biomass (t/ha) and carbon sequestration (tC/ha) against tree age (years) for YC 8, 16 and 24 Sitka spruce



Notes: MAI = mean annual increment (tC/ha/yr)

Source: Cannell and Cape (1991)

The growth/sequestration curves shown in Figure 8.2 only cover the period during which a particular plantation is growing. Clearly, once felled, much of the carbon locked up in a specific rotation will be liberated back to the atmosphere via decomposition, manufacturing wastage, or combustion. Indeed the end usage becomes the crucial factor determining the rate of carbon liberation (see subsequent discussions). However, if replanting occurs then the new trees will again begin to fix carbon.

An interesting long term factor in tree carbon storage analysis concerns the possibility of global warming feedbacks. The precise impacts of global warming upon tree growth is extremely difficult to predict. Two effects seem particularly important: increasing CO_2 levels; and climatic change.

In a review of existing literature Eamus and Jarvis (1989) report that studies have found that increased concentrations of CO_2 were found to enhance rates of tree growth although estimates of the extent of this effect were quite varied. Whilst not disagreeing with such findings, Cannell and Cape (1991) point out that the studies reviewed were all of short duration (less than 12 months) and that a long term adaption process whereby growth rates return to present levels is physiologically feasible. Nevertheless, most studies (e.g. Waggoner, 1983; D'Arrigo *et al.*, 1987) do point to some positive relationship between CO_2 and growth rate. In recent experiments, Heath *et al.*, (1995) reported that increasing concentration levels of CO_2 by 250 ppm over ambient levels of about 350 ppm, resulted in a 23% increase in growth rate for beech and 25% increase for oak. Murray *et al.*, (1995) examine the impact upon Sitka spruce and beech of raising CO_2 by 300 ppm in conjunction with varying nutrient levels, concluding that CO_2 elevation may have little impact at low nutrient levels but that at high nutrient levels such CO_2 elevation may raise biomass weight by about 35%.

Cannell and Cape (1991) examine the impact of a potential, climate change induced 1 C increase in UK temperature concluding that this will generally raise tree growth rates. However, they also stress that "less confidence may be put in the prediction that trees already growing in mild southerly and westerly locations will benefit from further warming" (p.23). Although a wider variety of species may become viable the authors highlight possible negative effects arising from global warming including damage to roots during dry summers. The potential for increased acid rain damage is also noted.

Given these uncertainties, global warming feedbacks are not incorporated within our subsequent carbon flux model. On balance it seems likely that such omissions will tend to result in some small underestimate of long term carbon sequestration. However, in the face of such considerable uncertainty and relative paucity of data we prefer to adopt this conservative stance.

(ii) Species

Carbon sequestration rates vary substantially between species. One reason for this, which we have already briefly mentioned, is the higher specific gravity (SG) of broadleaves as compared to conifers. Table 8.3 details SG for selected species including Sitka spruce and beech.[15]

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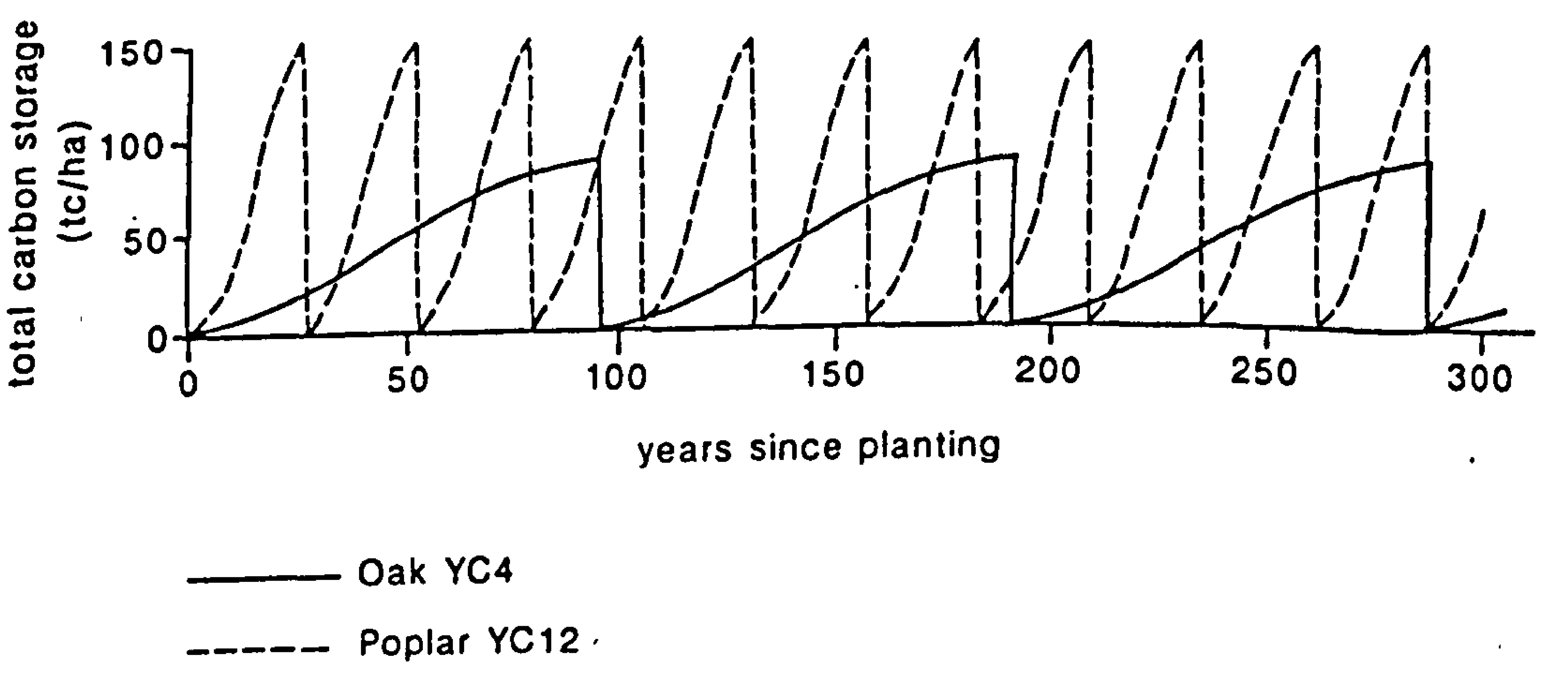
[15]Further details regarding SG for a variety of species are given in Lavers (1969).

Table 8.3: Specific gravity by species

Species	Specific Gravity
Sitka spruce	0.33
Corsican pine	0.40
Birch	0.53
Oak	0.56
Beech	0.56

As a result of differences in SG, two species growing at the same YC may well be fixing quite different levels of carbon. Also, as differing species have differing optimal felling ages (see Chapter 6), so the S-shaped growth curve for living wood will return to zero and restart its path at differing points in time. Dewar and Cannell (1992) illustrate this divergence for two species which are assumed to be replanted after felling to produce the saw-toothed tree carbon storage functions illustrated in Figure 8.3.

Figure 8.3: Tree carbon storage for two species



Source: Based on Cannell and Dewar (1992)

The temporal difference in cycle length across species will be particularly important when we consider discounted carbon storage values. Furthermore, as optimal felling date is itself a function of both YC and discount rate (see Chapter 6), it needs to be modelled as such within our carbon storage analysis.[16]

(iii) Management regime

Modern silvicultural practices have conflicting implications for tree carbon storage. As noted in our YC model (Chapter 7) modern intensive plantations produce higher growth rates than extensive and natural forest systems and it is generally believed that this raises carbon storage:

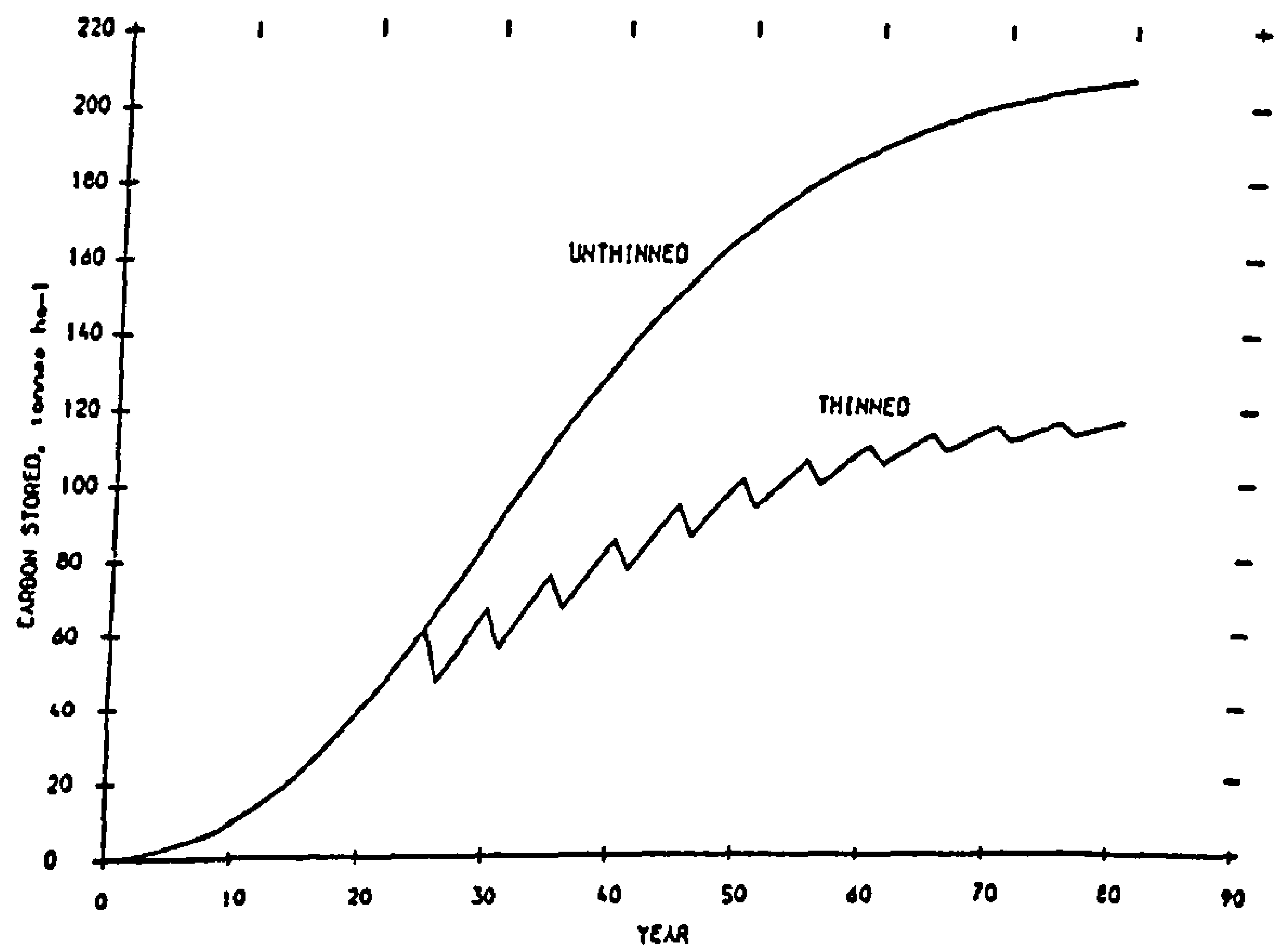
> "Moving from natural forest management to plantation-based strategies .... increases carbon fixation as foresters can plant trees of a type and in such a way as to maximise the rate of timber production"
>
> Thompson and Matthews (1989a, p.19)

There are some drawbacks of plantation style management techniques. One problem is that the move does imply certain emissions directly from forest management, particularly during felling. However, these are likely to be lower than those associated with agricultural land use and "several orders of magnitude" less than those associated with the manufacturing of wood products (Matthews, 1993).

A second, more important, effect arises from crop thinning, a technique typical of commercially managed plantations. Matthews (1993) compares newly planted 'unmanaged' woods with commercially managed plantations finding that the latter fix significantly less carbon than do the former (thus contradicting his earlier work with Thompson quoted above). This difference arises primarily as a result of thinning which affects long term carbon sequestration in two ways. Firstly, while thinning does result in remaining trees being of a greater girth, the number of stems is significantly reduced resulting in a lower biomass per hectare (see Figure 8.4). Secondly, thinnings tend to be put to brief lifetime end uses with short carbon-release dates (to which we turn subsequently).

[16]Optimal felling date is in fact a function of NPV which is in turn a function of YC and r. Strictly speaking the monetisation of net carbon storage benefits should be allowed to influence felling date (through impacts upon NPV). However, given the complexity of the necessary programming and that this would only be valid with respect to social as opposed to private forestry values, such an extension was not undertaken. Given the subsequently estimated values of carbon sequestration, any error will be small; a result confirmed in a recent analysis by van Kooten et al., (1995).

Figure 8.4: Simulated carbon storage by thinned and unthinned (YC12) Sitka spruce



Source: Matthews (1992)

Does this imply that all stands should be left unmanaged and that we should abandon consideration of thinning-based YC models? There are two reasons why this is probably not a wise move. Firstly, in the absence of carbon storage subsidy payments, both private producers and the EC have no incentive to adjust silvicultural practice to increase carbon storage[17]. A second reason is provided by Matthews (1993) who extends his analysis to consider the potential savings in terms of reduced emissions where commercially produced wood is used to substitute for existing carbon sources. Using information from Keighley (1983) regarding the burning efficiencies of coal and oil as opposed to spruce wood, Matthews shows that, providing the wood is burned as a direct substitute for fossil fuel, then "harvesting the forest for fuel is preferable to leaving the forest unmanaged" (p.6). Consideration of thinned forests therefore seems the correct option from both a pragmatic and theoretical standpoint.

8.2.3 CARBON LIBERATION FROM WOOD PRODUCTS

Once a tree is felled its fixed carbon store begins to be liberated back to the atmosphere as CO_2. This may occur quite quickly if the wood is used as fuel, left to

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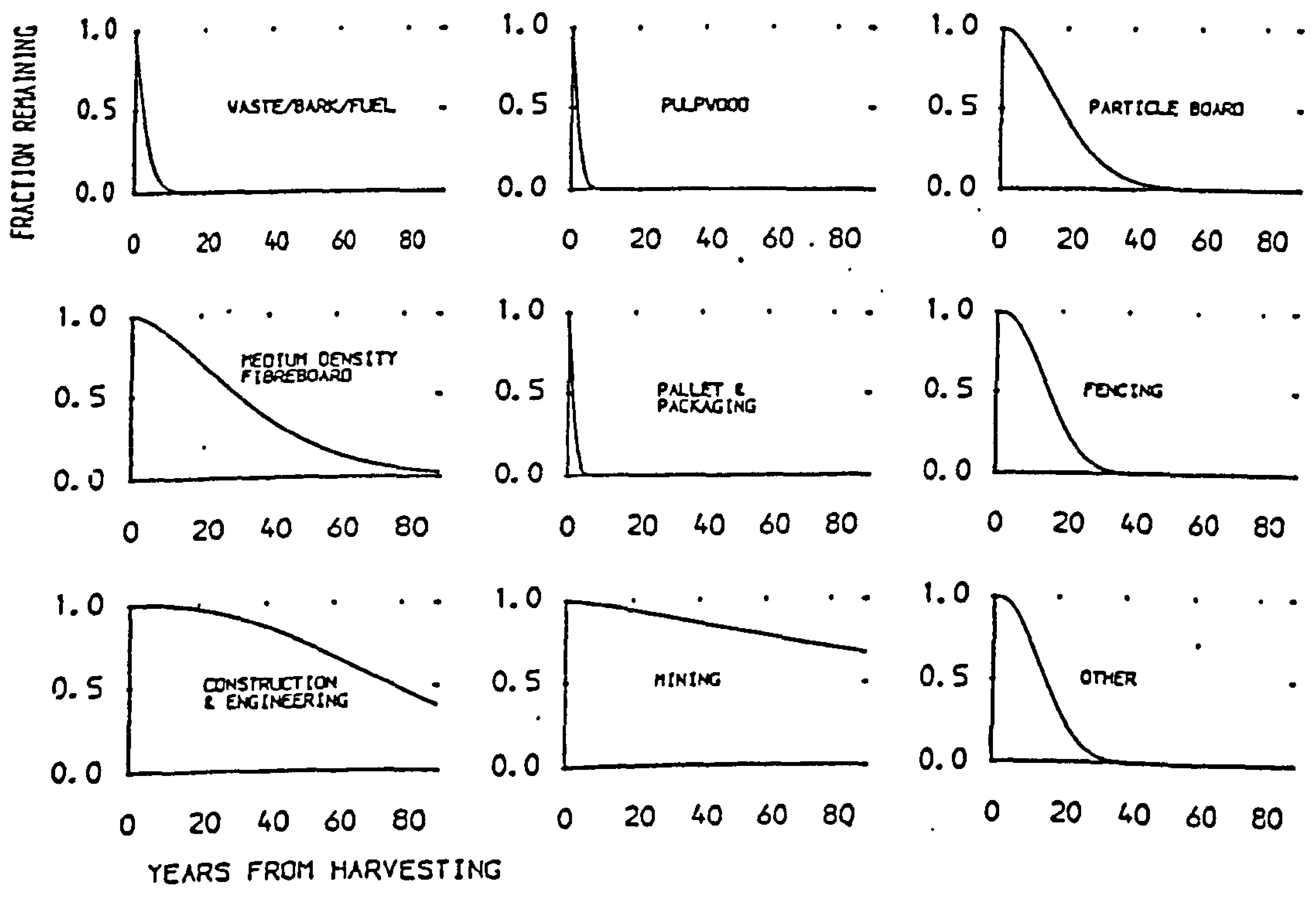
[17]Note that this differs from the case of non-market woodland recreation where private operators can receive subsidy payments and the EC has both a duty of provision and corresponding grant aid.

decompose (e.g. small trimmings), or used for short term purposes. The carbon liberation rates resultant from these various end-uses can vary substantially. For example, Thompson and Matthews (1989a) compare conventionally grown YC16 Corsican pine with short rotation coppice (SRC) Poplar plantations, noting that the latter fixes significantly more carbon per annum than the former. However, because SRC is generally used as fuel, its long term average sequestration rate is significantly lower than that of Corsican pine which is typically used for more enduring products[18].

A rigorous examination of the impact of end use upon carbon fixing is given in Thompson and Matthews (1989b). Results were obtained for a variety of species, those for Sitka spruce being graphically summarised in Figure 8.5[19].

Figure 8.5: Longevity of Sitka spruce timber when put to different uses



Source: Thompson and Matthews (1989b)

[18]Marland and Marland (1992) and Matthews (1993) highlight an important consequence of such examples: where timber is used as fuel and substitutes for existing high-carbon fossil fuels, a further net benefit will accrue. We have not adopted such an assumption in our analysis because of uncertainties regarding likely substitution rates. In effect we assume that capital commitments to non-timber fuelling systems mean that any conversion rate will be very low.

[19]Dewar and Cannell (1992) report product carbon liberation curves for Poplar and Oak.

Thompson and Matthews (1989a) also report mode and 95% carbon liberation periods for a variety of products and species as detailed in Table 8.4.

Table 8.4: Mode and 95% carbon liberation periods (years) for various timber products and species

Product	Years to specified carbon loss[1]							
	Sitka spruce		Corsican pine		Oak		Birch	
	Mode	95%	Mode	95%	Mode	95%	Mode	95%
Waste/bark/fuel[2]	1	8	1	8	2	18	1	6
Pulpwood	1	5	1	5	1	5	1	5
Particle board	15	40	15	40	15	40	15	40
MDP[3]	20	80	n/a	n/a	n/a	n/a	n/a	n/a
Pallet and packaging	1	4	2	5	2	5	1	5
Fencing	15	30	20	40	40	80	40	80
Construction and engineering	70	150	100	200	150	300	5	40
Mining	40	n/a	40	n/a	40	n/a	10	n/a
Other	15	30	20	40	40	80	10	20

[1] Mode = that year in which the largest annual carbon loss occurs.
95% = that year during which only 5% of carbon remains sequestered.
[2] For hardwoods observations are for waste wood only (i.e. excludes bark and fuel).
[3] MDF = medium density fibreboard.

Source: Adapted from Thompson and Matthews (1989a)

Given the findings of Figure 8.5 and Table 8.4 it is clear that end use has a major influence upon plantation average carbon storage levels. Indeed Matthews (1995) cites this as the major determinant of overall carbon storage, being significantly stronger than factors such as silvicultural management regime. Table 8.5 itemises end uses for Forestry Commission timber in 1991.

The final column of Table 8.5 draws upon Thompson and Matthews (1989b) to categorise end uses according to their longevity as follows:

S = short emission times: waste/bark/fuel; pulpwood; pallet and packaging

M = medium emission times: particle board; MDF; fencing; other

L = long emission times: construction and engineering; mining

Following this classification Table 8.5 indicates that roughly 30% of present UK production is consigned to short emission time end uses; 20% to medium term; and approximately 50% to long term end uses[20].

Table 8.5: Forestry Commission timber end use (1991)

End use	Volume (million m^3 under bark)	% of total volume	95% carbon liberation (years from felling)	Emission class[1] (see text)
Softwood sawn logs (mainly construction)	2.9	41.1	150	L
Hardwood sawn logs (construction and furniture)	0.6	8.5	300	L
Pit props (mining)	0.02	0.003	200	L
Particleboard	1.2	17.0	40	M
Fibreboard	0.02	0.003	80	M
Paper/cardboard	1.1	15.5	5	S
Other industrial wood	0.2	2.8	30	M
Fuel	0.2	2.8	5	S
Bark	0.8	11.5	5	S
Total (underbark + bark)	7.1	100.0	-	

Notes: [1] L = long; M = medium; S = short emission times (see text).

Source: Compiled from Thompson and Matthews (1989b); Cannell and Cape (1991); Forestry Commission (1992); Whiteman (1993) pers. comm.

8.2.4 CARBON FLUX IN SOILS

8.2.4.1 Determinants of soil carbon levels

All soils contain a certain natural level of carbon. This generally consists of decaying soils organic matter (SOM) although a small amount (usually less than 5%) is held as soil organisms (Jenkinson, 1988). On uncultivated soils a number of natural factors influence soil carbon content including: soil texture; moisture; temperature; and the lignin content of the natural plant cover (Parton *et al.*, 1987). In lowland areas the quantity and type of organic material returned to the soil as dead plant tissue is, in the long run, balanced by the decomposition of SOM and release of CO_2 and water (Jenkinson, 1988). Such soils are therefore in carbon balance. However, soils which are poorly drained and frequently waterlogged (typically in upland areas) exhibit very slow decomposition rates[21]. Where organic deposition exceeds decomposition peat is formed (Askew *et al.*, 1985). Such soils have no predetermined upper limit upon SOM levels (although average levels can be

[20] A further issue, considered by Matthews (1992), is the level of manufacturing emissions associated with differing end uses. These are relatively high for capital intensive products such as paper and low for sawn wood, etc.

[21] Harrison *et al.*, (1995) report a strong negative relation between soil moisture deficit and carbon content. See also Edwards (1975).

calculated) and consequently may have very high carbon contents (Adger *et al.*, 1992).

On cultivated soils a variety of additional factors may influence soil carbon levels including: tillage regime; crop selection; addition of fertilizer and organic matter; irrigation; and residue treatments[22] (Parton *et al.*, 1987). The transition from uncultivated to intensive arable land, particularly where bare fallow rotation systems are used, is commonly associated with very significant losses in SOM. The majority of a soils carbon is held near the surface and repeated tillage exposes the SOM to the atmosphere increasing decomposition rates significantly above natural levels (Jenkinson, 1988). Tiessen *et al.*, (1982) reports a 35% loss in carbon levels over a 70-year period as a result of switching grassland into cropping[23]. Jenkinson (1988) reports a similar loss over roughly 30 years for an area of old established grassland switched into various arable crops, losses being greatest where land was regularly ploughed with no crop cover being sown.

The growth of intensive agriculture worldwide during the twentieth century has led to massive depletions in soil carbon levels. The extent of these depletions has provided a major source of global CO_2 emissions:

> "soil carbon losses have been a primary anthropogenic source of carbon dioxide, second only to fossil fuel combustion in contributing to historical increases of global carbon dioxide concentrations"
>
> Post *et al.* (1990)

Concern regarding the global impact of soil carbon loss has recently led to the instigation, by the US Environmental Protection Agency (EPA), of the BIOME project; a research initiative examining "the degree to which agroecosystems can be technically managed, on a sustainable basis, to conserve and sequester carbon, thereby reducing the accumulation of CO_2 in the atmosphere" (Barnwell *et al.*, 1991).

8.2.4.2 Afforestation and soil carbon

Until recently relatively little work had been done on the long term effects of

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[22] For example, whether or not stubble is burned.

[23] Clay and silt loam soils. Use of leguminous crops reduced losses from 35% to 18% (Tiessen *et al.*, 1982).

afforestation upon soil carbon levels in the UK[24]. An important early exception is provided by the work of Jenkinson (1971, 1988) who examined two areas which had been arable for many years before being abandoned and allowed to revert to woodland for some 80 years. This natural afforestation resulted in very considerable increases in soil carbon as detailed in Table 8.6.

Table 8.6: Soil carbon increases over an 80-year period from natural afforestation

Site	Initial soil carbon level (tC/ha)	Final soil carbon level (tC/ha)	Increase over 80 years (tC/ha)
Broadbalk	60	110	50
Geescroft	61	81	20

Source: Jenkinson (1971)

Matthews (1993), in his model of Sitka spruce forest carbon budgets, combines the work of Jenkinson with that of Whitehead *et al.*, (1975) and Wilson (1991) in formulating his soil carbon flux predictions[25]. Here soil is assumed to have previously been under intensive cropping resulting in an initial, pre-afforestation, soil carbon content of 30 tC/ha. This is assumed to rise to approximately 70 tC/ha some 200 years after planting and reach a subsequent maximum of 100 tC/ha. Similar results are reported by Sampson (1992) in a study of two US sites which exhibit long term soil carbon equilibrium increases of about 50 tC/ha arising from afforestation.

In a study using similar soil and management conditions, Dewar and Cannell (1992) report soil carbon storage curves for hardwoods which are similar to those of Matthews (1993) suggesting that there is not a particularly significant species effect here. However, other factors can have very substantial impacts upon soil carbon flux.

The major determinants of soil carbon change under afforestation are soil type and

[24]Conversations with Professor David Jenkinson and Professor Steven McGrath at Rothamsted Experimental Station (1993) confirmed the apparent lack of contemporary research into this area.

[25]A further assumption, that clear felling will not reduce soil carbon providing replanting occurs within one year, is also made by Matthews (1993) with reference to the work of Edwards and Ross-Todd (1983). However, recent work by Harrison *et al.*, (1995) suggests that SOM may decline during the first 15 years following replanting after which SOM begins to rise again slowly taking anything up to 60 years to return to equilibrium. See also Adger and Brown (1994).

prior usage[26]. From these we can estimate present carbon levels and predict long term equilibrium levels under afforestation. McGrath and Loveland (1992) estimate organic carbon concentrations (%) for eight soil types as detailed in Table 8.7.

Table 8.7: Soil carbon levels (%) for various soil types[1]

Major soil groups	No. of samples	Minimum	Lower hinge	25th percentile	50th percentile	75th percentile	Upper hinge	Maximum
Lithomorphic soils	397	0.2	0.2	2.7	4.5	8.4	16.9	61.5
Pelosols	262	1.0	1.0	1.9	2.8	4.4	7.8	19.1
Brown soils	2116	0.1	0.1	1.8	2.8	4.1	7.5	22.4
Podzolic soils	488	0.8	0.8	4.0	6.0	10.5	19.9	53.3
Surface-water gley soils	1409	0.6	0.6	2.5	3.8	5.8	10.6	58.3
Ground-water gley soils	614	0.8	0.8	2.5	4.0	6.8	13.2	54.5
Man-made soils	138	0.2	0.2	2.1	3.3	5.0	8.9	3.10
Peat soils	204	<12.0	<12.0	28.6	46.2	50.3	65.9	65.9
All soils	5666	0.1	0.1	2.3	3.6	5.9	11.3	65.9

Note: [1] Calculated on a dry soil basis.

Source: McGrath and Loveland (1992)

The proportional carbon estimates given in Table 8.7 can now be related to absolute carbon storage levels. However, this will vary according to land use. Adger *et al.*, (1992) report equilibrium soil carbon levels for a variety of soils and land uses as detailed in Table 8.8.

The work of Adger *et al.*, (1992) gives us further information regarding the soil carbon implications of agriculture to forestry conversions across a variety of soil types. However, the matrix of possibilities is somewhat incomplete and so the equilibrium levels quoted in Adger *et al.*, (1992) were combined with information gathered in conversations with Professor David Jenkinson (Rothamsted), Dr Robert Sheil (University of Newcastle upon Tyne), and Professor Steven McGrath (Rothamsted) to produce estimates of the full range of changes which could occur through afforestation of various soil types. This analysis was extended to consider both lowland and upland areas which, because of varying rainfall and land use, may

[26]The SSLRC LandIS system provides the best source of soil type data for England and Wales. Land use data may be obtained from the ITE/NERC database. Furthermore, 5 km soil property, nutrient and elements maps are provided in McGrath and Loveland (1992) although the data supporting these maps was not available for this study. Alternative approaches include use of the CORINE land cover database (EU, 1992) as employed by Cruikshank *et al.*, (1995).

exhibit significantly different rates of soil carbon accumulation. Table 8.9 presents results from this analysis.

Table 8.8: Equilibrium soil carbon levels for various soils under different land uses

Land use	Additions to soil (tC/ha)	Non-harvested biomass (tC/ha)	Soil type	Equilibrium soil carbon (tC/ha)
Broadleaved woodland	0-5.0†	0-164	G	170
Coniferous woodland	0-4.0†	0- 95	SHP	450
Mixed woodland	0-4.5†	0-129	GSH	250
Upland heath	0.9	2.4	SZ	200
Upland smooth grass	2.0	2.0	GSH	180
Upland coarse grass	1.3	3.2	HPS	400
Blanket bog	0.7	3.2	P	1200‡
Bracken	1.5	1.6	SZ	200
Lowland rough grass	2.1	2.4	G	120
Lowland heath	1.0	1.6	Z	80
Crops	2.7	0.0	BG	60
Market garden	1.5	0.0	B	50
Improved grass	3.9	1.6	GB	90
Rough pasture	1.4	2.9	HSP	350
Neglected grassland	2.1	2.4	GS	120
Built up§	0.4	1.2	BGP	10
Urban open spaces§	1.2	4.0	GBP	70
Transport§	0.4	1.0	-	70
Mineral workings§	0.4	0.8	-	90
Derelict§	0.8	2.0	-	120

† Excluding final harvest waste. ‡ No upper limit. § Not in primary land use sector. Soil types (from Avery, 1980): G, stagnogley; S, humic stagno podsol; H, humic gley; P, peat; Z, podsol; B, brown earth.

Source: Adger *et al.*, (1992)

Inspection of Table 8.9 shows that afforestation is generally synonymous with long term increases in soil carbon storage levels and that these increases are liable to be somewhat larger in lowland sites due to the prevalence of more intensive prior agricultural land uses. The one clear exception to this trend arises where planting occurs on previously unplanted peat soils. Here the extremely high prior levels of soil carbon are substantially reduced by the planting and tree growth processes[27] (Harrison *et al.*, 1995; Davidson and Grieve, 1995).

[27]This process is similar in nature (although far more extreme) to the loss of lowland SOM through intensive agriculture noted previously (Post *et al.*, 1990).

Table 8.9: Post-afforestation changes in equilibrium: soil carbon storage levels for various soils previously under grass (tC/ha): upland and lowland sites

Soil type	Upland sites			Lowland sites		
	Under grass	Under trees	Change	Under grass	Under trees	Change
Peat	1200	450	(750)	n/a	n/a	n/a
Humic gley	180-400	250-450	50-70	180-350	180-450	0-100
Podzol	200-400	250-450	50	100-200	100-450	0-250
Brown earths	n/a	n/a	n/a	100-120	100-250	0-130
Humic stagno podzol	180-400	250-450	50-70	120-350	120-450	0-100
Stagnogley	170-400	170-450	0-50	100-120	100-450	0-330

Notes: 1. Use prior to afforestation is assumed to be long established agricultural pasture (dairy, cattle or sheep).
n/a = not applicable; soil type not common at this altitude.
Brackets indicate negative amounts.

Source: see text.

Given the impact of discounting upon our subsequent valuations of carbon flows, the shape of the soil carbon flux function is clearly important. The general consensus is that marginal soil carbon flux is relatively high in the years following initial planting and declines smoothly to reach equilibrium over some extended period (Cannell and Milne, 1995). Robert Shiel (pers. comm., 1994) suggests that roughly 95% of the net change in soil carbon will occur within 200 years of planting. Both Matthews (1993) and Dewar and Cannell (1992) illustrate total soil carbon storage curves which have negative exponential shapes. Combining these pieces of information allows us to model both total and marginal soil carbon storage curves.

8.3 METHODOLOGY

Our objective is to assess and quantify the amount of carbon stored in trees, soils and products, and then value this storage using the unit values discussed previously. This exercise is complicated by the fact that the carbon flux initiated by afforestation is both complex (involving carbon sequestration by trees and non-peaty soils, and carbon liberation from products, felling waste and peaty soils) and occurs over a very extended period. The complexity of an overall carbon flux function means that benefits (sequestration) and costs (liberation) occur at various points in time. Furthermore, temporal considerations mean that the discounting issue will also be pertinent here. Choice of appropriate modelling methodology is therefore crucial if we are to accurately assess the carbon flux initiated by afforestation, indeed Matthews (1995) argues that the adoption of differing methodologies is the prime factor explaining the variety of estimates which he reviews in that paper.

One apparently straightforward solution to these problems is to use long term average net sequestration estimates. Table 8.10 details average total and first rotation marginal (per annum) carbon storage in trees, products and soils for a variety of species and yield classes.

Table 8.10: Carbon storage characteristics of different forest types in Britain

Forest type (yield class: m^3/ha/yr)	Rotation length (years)	Long-term average amount of carbon in trees and products (equilibrium storage) (tC/ha)	Long-term average amount of carbon in trees, products, litter and forest soil (equilibrium storage) (tC/ha)	Net annual carbon flux over the first rotation (rate of storage) (tC/ha/yr)
Sitka spruce (24)	47	98	211	4.4
Sitka spruce (20)	51	94	208	4.1
Sitka spruce (16)	55	86	192	3.6
Sitka spruce (12)	59	74	167	3.0
Sitka spruce (8)	65	61	146	2.4
Poplar (12)	26	102	212	7.3
Willow coppice (-)	8	22	93	5.9
Nothofagus (16)	28	57	179	4.6
Scots pine (10)	71	79	178	2.7
Lodgepole pine (8)	62	63	155	2.5
Beech woodland (6)	92	85	200	2.4
Oak woodland (4)	95	67	154	1.8

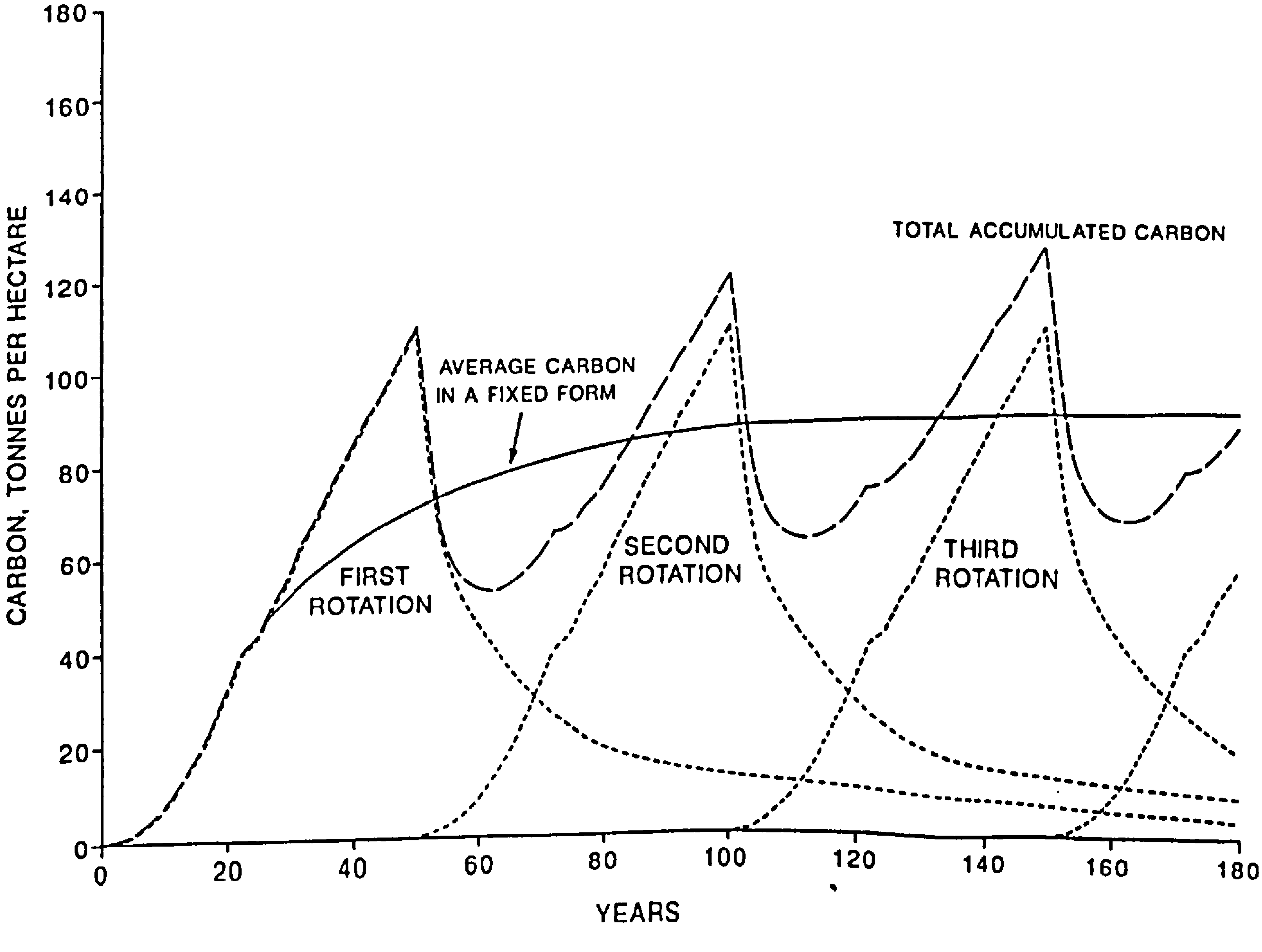
Note: The data for Sitka spruce refer to stands subject to intermediate thinning.

Source: Dewar and Cannell (1992)

While the information given in Table 8.10 provides an indication of the magnitude of carbon storage, average quantities are only crude measures and unsuitable for economic analysis. In particular the marginal storage rates detailed in Table 8.10 would result in substantial overstatement if used to estimate carbon storage benefits. This is because they are constant across the first rotation implying that carbon storage is as high in the year of planting as it is say at mid-rotation. Given that the practice of discounting places a weight of 1 upon net benefits received in the year of planting and progressively lower weights upon those received subsequently, the use of average carbon storage quantities will result in substantial overestimates of the net present value of sequestration. Furthermore, as carbon from the first rotation begins to be liberated from the date of felling, net marginal sequestration rates will not be the same in the second rotation as in the first. Indeed, they will be substantially lower.

A superior approach to modelling net carbon storage in trees and products is adopted by Pearce (1991-1994) who provides the only published UK study of forestry sequestration values to date. Matthews (1991) and contemporary unpublished work by Thompson and Matthews at the Forestry Commission's Alice Holt Lodge Research Station estimates moving averages for total carbon storage across rotations as illustrated by the solid line in Figure 8.6.

Figure 8.6: Moving average total carbon storage in trees and products: Sitka spruce YC16



Source: Pearce (1991)

Pearce implicitly assumes that the moving average total carbon curve gives a reasonable approximation of the total carbon storage curve and models this as the negative exponential given in equation (8.1).

$$TCF = M(1 - e^{-gt}) \tag{8.1}$$

where

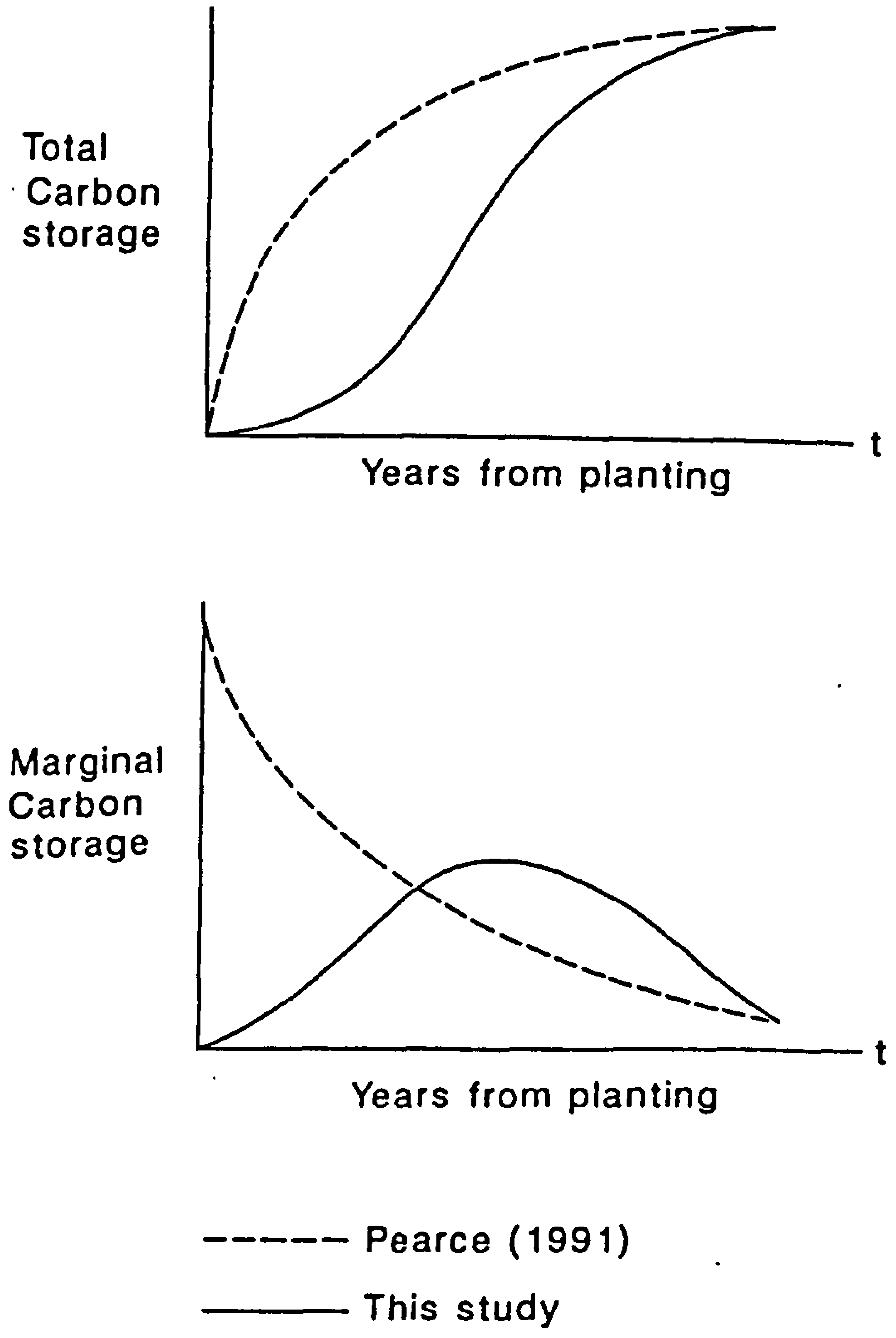
TCF	=	total carbon storage at t
M	=	equilibrium total carbon storage ($M = F$ at $t = \infty$)
g	=	rate of carbon storage (per annum)
t	=	year (0 to ∞)

For evaluation purposes we are interested in marginal (annual) carbon storage which is simply the differential of (8.1) as shown in equation (8.2)

$$\text{marginal carbon storage} = \frac{dF}{dt} = Mge^{-gt} \tag{8.2}$$

While this represents a considerable improvement over the use of simple averages discussed above, it still has some of the same drawbacks. Figure 8.7 illustrates our point by concentrating solely upon the first rotation prior to felling (where all carbon is stored as trees). The upper panel shows in dashed line the total carbon storage curve estimated by Pearce (1991) using equation (8.1) while the dashed line in the lower panel shows the corresponding marginal carbon storage curve from equation (8.2). This lower curve shows the flaw in such an approach as it implies that marginal carbon storage is at a maximum in the year of planting and declines thereafter. A more realistic model is presented by the solid lines which show, in the upper panel, that total carbon storage follows a sigmoidal curve implying the domed marginal carbon storage curve of the lower panel.

Figure 8.7: Total and marginal tree carbon storage curves in the first rotation



The overestimate of marginal carbon storage implicit in the Pearce approach will be exacerbated by the effects of discounting which will tend to emphasise the relative importance of these early years. Nevertheless it should be noted that the Pearce approach is a considerable improvement upon the use of simple averages and, by combining tree and product carbon and employing a relatively straightforward function form, avoids the complexities of our own approach to which we now turn.

Our own approach is to separate out the tree, product and soil elements of carbon flux and model each individually. In each case total carbon flux curves are estimated from which marginal annual increments are obtained. Where these are positive (as in the case of tree carbon and non-peaty soils) they are monetised to produce benefit values. Conversely where previously stored carbon is liberated (as in the case of peaty soils and forest products, within which we include felling waste) these produce monetary costs.

Comparison of these benefits and costs yields a stream of undiscounted net benefits which can then be discounted to produce net present value sums for any desired time frame. Unlike our timber yield valuations, we no longer have a simple replication of the first rotation. Ongoing liberation of carbon stored in earlier rotations and the approach of a post-afforestation soil carbon equilibrium mean that the net sequestration benefits of successive rotations decline over time[28]. Because of this, NPV for the first rotation is higher than in subsequent rotations. This supports the use of annuity equivalents based upon continual replanting after felling. Given that we do not have a repeated pattern to our overall carbon storage function, the annuity function used in Chapter 6 needs to be revised. Brealey and Myers (1984) give formulae relating present values to annuities which we can rewrite as per equation (8.3) which applies to exponential discounting:

$$\text{Annuity (exponential)} = \frac{NPV_{perpetuity}}{\left[\frac{1}{r} - \frac{1}{r(1+r)^t}\right]} \tag{8.3}$$

For hyperbolic discounting our annuity formula is given by equation (8.4):

$$\text{Annuity (hyperbolic)} = \frac{NPV_{perpetuity}}{\left[\frac{1}{r} - \frac{1}{r(1+rt)}\right]} \tag{8.4}$$

8.4 MODELLING CARBON STORAGE IN TREES

8.4.1 CARBON STORAGE IN SITKA SPRUCE LIVE WOOD

In order to avoid the problems of over-estimating marginal carbon benefits in the early years of a rotation, the negative exponential total carbon storage curve used by Pearce (1991) is rejected in favour of the S-shaped growth curve characteristic of all unthinned crops.

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[28]In essence the overall land use carbon storage moves over time to a new equilibrium. This of course does not mean that replanting can then be discontinued as such a decision would result in a return to the pre-afforestation level of carbon storage.

Figure 8.4 illustrates such a function but also shows the importance of allowing for the impact of thinning upon carbon storage. In thinned crops the total carbon storage curve is non-linear, following the unthinned S-shaped growth curve up to the date of first thinning (TD1) after which a significantly shallower path is followed up to the felling date (F). Figure 8.8 illustrates these curves for various yield classes of Sitka spruce.

Figure 8.8: Total carbon storage curves for unthinned and thinned Sitka spruce (r = 5%)

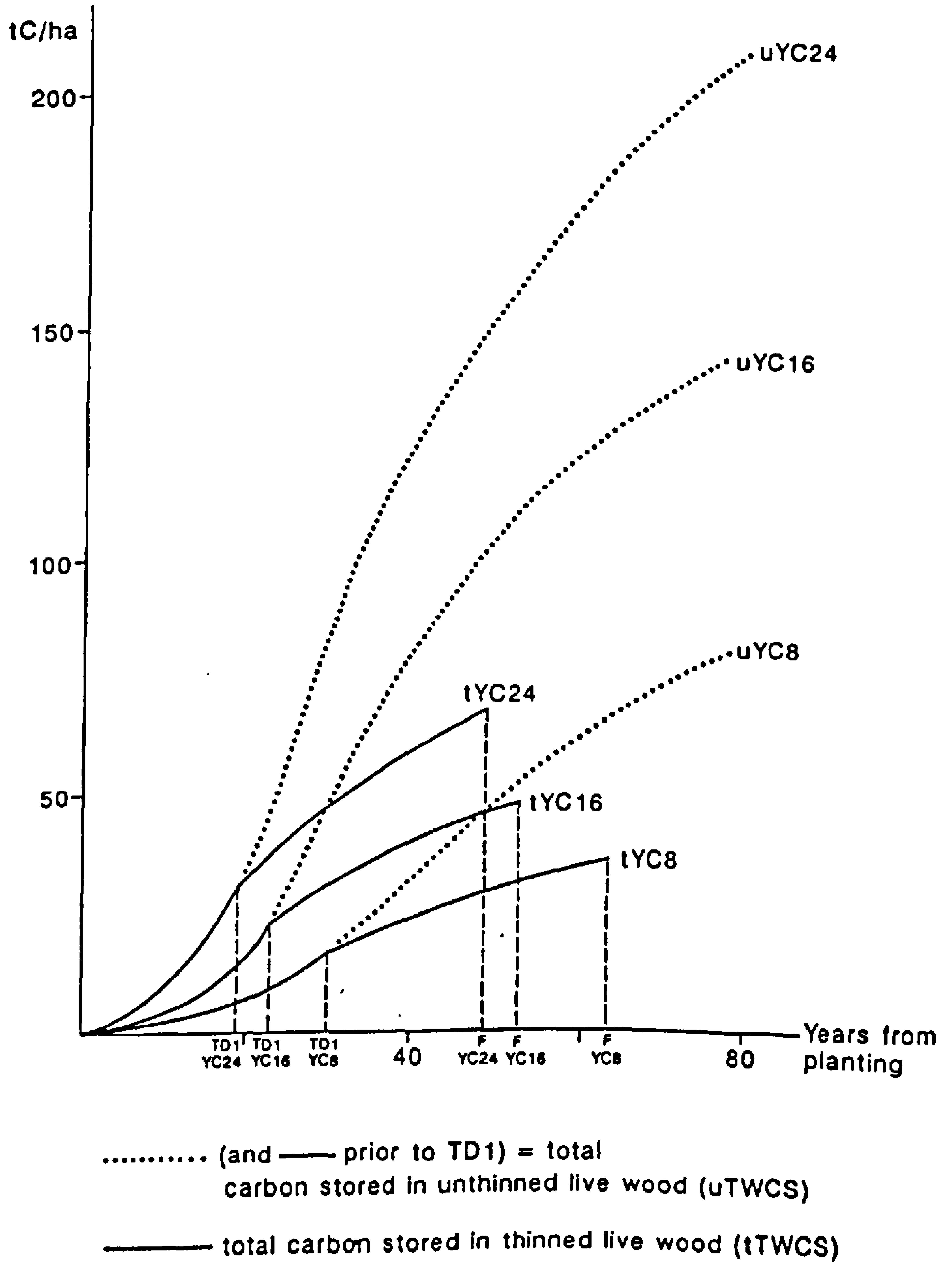


Figure 8.8 illustrates some of the complexities involved in modelling tree carbon storage even within a single species. From Cannell and Cape (1991; see Figure 8.2) we can see that carbon storage rises in a linear manner across yield class. However, for any given

yield class, the impact of thinning upon carbon storage is substantial. This impact is triggered by TD1. However, both this and F are, as shown in Chapter 6, functions of yield class and discount rate (the latter being held constant in Figure 8.8). Carbon storage modelling therefore needs to reflect this complex interaction of diverse factors.

We start the modelling process by considering the S-shaped curve which is total carbon storage in unthinned live wood (uTWCS). This can be modelled as the cubic given in equation (8.5):

$$uTWCS_{iYC} = \beta_{1iYC} + \beta_{2iYC}t + \beta_{3iYC}t^2 + \beta_{4iYC}t^3 \tag{8.5}$$

where:

i	=	species (for Sitka spruce i = SS; for beech i = BE)
YC	=	(for i = 1) 4, 6, 8 26
t	=	years from planting (t = 0, 1, 2 .... F)

A priori we would expect $\beta_1 = 0$; $\beta_2 > 0$; $\beta_3 > 0$; and $\beta_4 < 0$. In order to estimate equation (8.5) data for Sitka spruce YC12 were taken from Matthews (1992, 1993). This data is based upon a superior total/merchantable volume function than that used in Matthews (1991) upon which the estimates of Pearce (1991) are based. Initial investigations confirmed that an optimal statistical model based on equation (8.5) gave estimates of β_1 which were insignificantly different from zero (as per expectations) and so this element was dropped from our final model which is reported as equation (8.6).

$$\underset{}{uTWCS_{SS,12}} = \underset{(4.40)}{0.43727t} + \underset{(28.09)}{0.10747t^2} - \underset{(-29.21)}{0.0010267t^3} \tag{8.6}$$

$R^2 = 99.9\%$ $n = 81$ Figures in brackets are t-statistics.

Not surprisingly, given the predictability of tree growth patterns, the model reported in equation (8.6) fits the data extremely well. All parameter estimates are very highly significant ($p < 0.000$ in all cases) and coefficients have expected signs and magnitudes.

We now need to generalise across yield classes. As noted in our literature review, Cannell and Cape (1991) show that carbon storage varies linearly across YC. We can therefore derive a species specific YC adjustment factor A_{iYC} which allows us to adjust from the YC of our baseline data (YC12) to any other Sitka spruce YC. Using the data given in Cannell and Cape (1991) we derive the Sitka spruce adjustment factor given in equation (8.7)[29]:

$$A_{SS,YC} = 0.08333 \text{ YC} \tag{8.7}$$

A generalised function for $uTWCS_{iYC}$ for i = SS and any YC can then be derived as per equation (8.8):

$$uTWCS_{SS,YC} = A_{SS,YC} * uTWCS_{SS,12} \tag{8.8}$$

These functions will continue to rise until t = F (the felling date). However, as noted, F is a complex function of both the discount rate (r) and YC. This relationship was investigated using YC/discount rate analysis of optimal felling dates reported in Chapter 6. Our resultant best fit model is detailed in equation (8.9):

$$\begin{array}{llllll} F_{SS,YC} = 114.43 & - 997.3\, r & + 7167\, r^2 & - 2.8657\, YC & + 0.05919\, YC^2 \\ \quad (32.67) & (-6.25) & (3.62) & (-9.21) & (5.79) \end{array} \tag{8.9}$$

$R^2 = 96.6\%$ n = 39 Figures in brackets are t-statistics.

Equation (8.9) fits the data extremely well with all parameters significant at $p = 0.001$ or better. It shows as noted previously that F declines with r (expressed as a decimal in equation (8.9)) and YC, although the clear significance of the quadratic terms in (8.9) shows that this is not a simple straight-line relationship.

We can now begin to move from unthinned to thinned crops. To do this we first need to estimate TD1. Examination of the yield models given in Edwards and Christie (1981) shows a clear relationship between TD1, F and YC. Table 8.11 reports this data for the relevant thinned Sitka spruce models detailed by Edwards and Christie (1981).

[29]Note that when YC = 12 then $A_{SS,12} = 1.0$.

Table 8.11: Date of first thinning (TD1) for Sitka spruce yield models (2 m spacing: no delay in thinning; r = 0.05 throughout)

YC	Year of first thinning[1] (TD1)	Optimal felling year[2] (F)	Ratio (TD1/F)
6	33	68	0.485
8	29	67	0.433
10	26	64	0.406
12	24	58	0.414
14	22	54	0.407
16	21	51	0.412
18	20	50	0.400
20	19	50	0.380
22	18	49	0.367
24	18	48	0.375

Sources: 1. = Edwards and Christie (1981)
2. = from Chapter 6, this study

Inspecting table 8.11 shows that TD1 falls as both F and YC increase. One simple method of capturing this relationship is to first model the ratio TD1:F as a function of YC as shown in equation (8.10):

$$RATIOTD1_{SS,YC} = \underset{(32.21)}{0.48149} - \underset{(-5.27)}{0.0049061}\ YC \qquad (8.10)$$

where:

RATIOTD1 = Ratio of TD1 to F

$R^2 = 77.7\%$ $n = 9$ Figures in brackets are t-statistics

While the small sample size used in equation (8.10) somewhat reduces the degree of explanation, individual t-statistics are very highly significant and, as no further data is available, this seems a reasonable approach. TD1 can then be calculated for any given YC by multiplying the corresponding felling date by equation (8.10) as shown in equation (8.11):

$$TD1_{SS,YC} = [0.4815 - (0.004906 * YC)] * F_{SS,YC} \qquad (8.11)$$

As shown in figure 8.8, once thinning commences total tree carbon storage falls progressively below that predicted by our uTWCS function. Using data from Matthews (1991, 1992, 1993) we can measure this proportion as the Thinning Factor (TF) detailed in the final column of table 8.12.

Table 8.12: Thinning factor (TDF) for Sitka spruce YC12

Years after date of first thinning ($t^* = t\text{-}TD1$)	Total unthinned tree carbon storage (tC/ha) ($uTWCS_t$)	Total thinned tree carbon storage (tC/ha) ($tTWCS_t$)	Reduction in total potential tree carbon storage arising from thinning (tC/ha)	Thinning factor $\left[TF = \frac{TWCS_t}{uTWCS_t}\right]$
0	50	50	0	1.00
5	67	55	12	0.83
10	84	61	23	0.73
15	109	71	38	0.65
20	133	82	51	0.62
30	169	95	74	0.56
40	192	107	86	0.56
50	206	116	90	0.56
60	211	120	91	0.56

Source: based on data in Matthews (1991, 1992, 1993)

Statistical investigation showed that TF_{SS} could be well predicted by the natural log of t^* where $t^* = t\text{-}TD1$. Equation (8.12) details our best fitting model of TF_{SS}.

$$TF_{SS} = \underset{(37.90)}{1.000} - \underset{(-13.41)}{0.1158} \ln t^* \qquad (8.12)$$

$R^2 = 96.3\%$ $\quad n = 8$ $\quad$ Figures in brackets are t-statistics

Note that where $t^* < 0$ (i.e. before $t = TD1$) we constrain TF to equal 1.

We are now able to calculate total live wood tree carbon storage for thinned stands of Sitka spruce ($tTWCS_{SS,YC}$) as per equation (8.13).

$$tTWCS_{SS,YC} = uTWCS_{SS,YC} * TF_{SS} \qquad (8.13)$$

The function shown in equation (8.13) grows in each year from planting to felling after which replanting is assumed to follow within one year and the function returns to zero and restarts its growth path.

Given that the model detailed in equations (8.13) (and subsequently in equation (8.21)) is discontinuous it cannot readily be differentiated. Consequently marginal carbon storage was calculated by solving equation (8.13) (and (8.21)) iteratively for each year in our time series and calculating the annual addition as storage[30].

8.4.2 CARBON STORAGE IN BEECH LIVE WOOD

The modelling of carbon storage in beech live wood followed the methodology used for Sitka spruce and will therefore be only briefly described. Information regarding sequestration in beech is somewhat sparser than for its widespread coniferous cousin, so much so that our analysis is based upon the estimates for oak (YC4) given in Dewar and Cannell (1992) adjusted by consulting the YC4 model for beech given in Edwards and Christie (1981). This exercise reinforced the findings of George Matthews (1993) who suggests that, within YC bands, carbon storage for oak and beech will be similar. Using this approach, observations on the S-shaped unthinned carbon storage curve $uTWCS_{BE,4}$ were built up for use in the estimated model which is reported in equation (8.14):

$$uTWCS_{BE,4} = \underset{(2.17)}{0.2414\, t} + \underset{(13.73)}{0.030752\, t^2} - \underset{(-13.24)}{0.00014252\, t^3} \qquad (8.14)$$

$R^2 = 99.9\%$ $\quad n = 26$ $\qquad$ Figures in brackets are t-statistics

[30]Care was taken to ensure that restarting of the growth path following felling was not recorded as a fall in tree carbon storage. All carbon liberation is captured by the function relating to felling waste and timber products.

As with Sitka spruce, the model of total carbon storage in unthinned beech live wood fits the data very well. All parameter estimates are highly significant ($p < 0.05$ for t and $p < 0.000$ for t^2 and t^3) and coefficients have expected signs and magnitudes (the latter differing logically from those of our Sitka spruce model).

As before we can calculate an adjustment factor ($A_{i,YC}$) to allow comparison between YC as per equation (8.15)[31].

$$A_{BE,YC} = 0.25\ YC \tag{8.15}$$

A generalised function for $uTWCS_{i,YC}$ for i = BE and any YC can then be derived as per equation (8.16).

$$uTWCS_{BE,YC} = A_{BE,YC} * uTWCS_{BE,4} \tag{8.16}$$

We now estimate F for beech as a function of r and YC using the data reported in Chapter 6. Our best fit model is reported as equation (8.17).

$$F_{BE,YC} = \underset{(20.78)}{173.86} - \underset{(-18.07)}{1901.4\ r} + \underset{(11.99)}{8870.8\ r^2} - \underset{(-2.25)}{5.387\ YC} + \underset{(1.47)}{0.2500\ YC^2} \tag{8.17}$$

$R^2 = 97.8\%$ $n = 31$ Figures in brackets are t-statistics

Equation (8.17) fits the data very well and reconfirms the relationships noted regarding the Sitka spruce data. All estimates are significant at $p < 0.05$ or better with the exception of the YC^2 term which has $p = 0.152$. While this is in itself insignificant the term is retained both for comparison with our previous model because it yields a slight improvement in adjusted model fit.

The year of first thinning (TD1) is also estimated as before. Table 8.13 details the data for this analysis. As can be seen, the lack of variation in YC for British beech considerably reduces the number of observations available.

[31]Note that when YC = 4 then $A_{BE,4} = 1.0$.

Table 8.13: Date of first thinning for beech yield models (1.2 m spacing, no delay in thinning, r = 0.05 throughout)

YC	Year of first thinning[1] (TD1)	Optimal felling year[2] (F)	Ratio (TD1/F)
4	35	81	0.432
6	30	75	0.400
8	25	71	0.352
10	25	69	0.362

Sources: 1. = Edwards and Christie (1981)
2. = from Chapter 6, this study

As before we now estimate $RATIOTD1_{BE,YC}$ as detailed in equation (8.18).

$$RATIOTD1_{BE,YC} = \underset{(15.29)}{0.47666} - \underset{(-3.03)}{0.012861}\ YC \qquad (8.18)$$

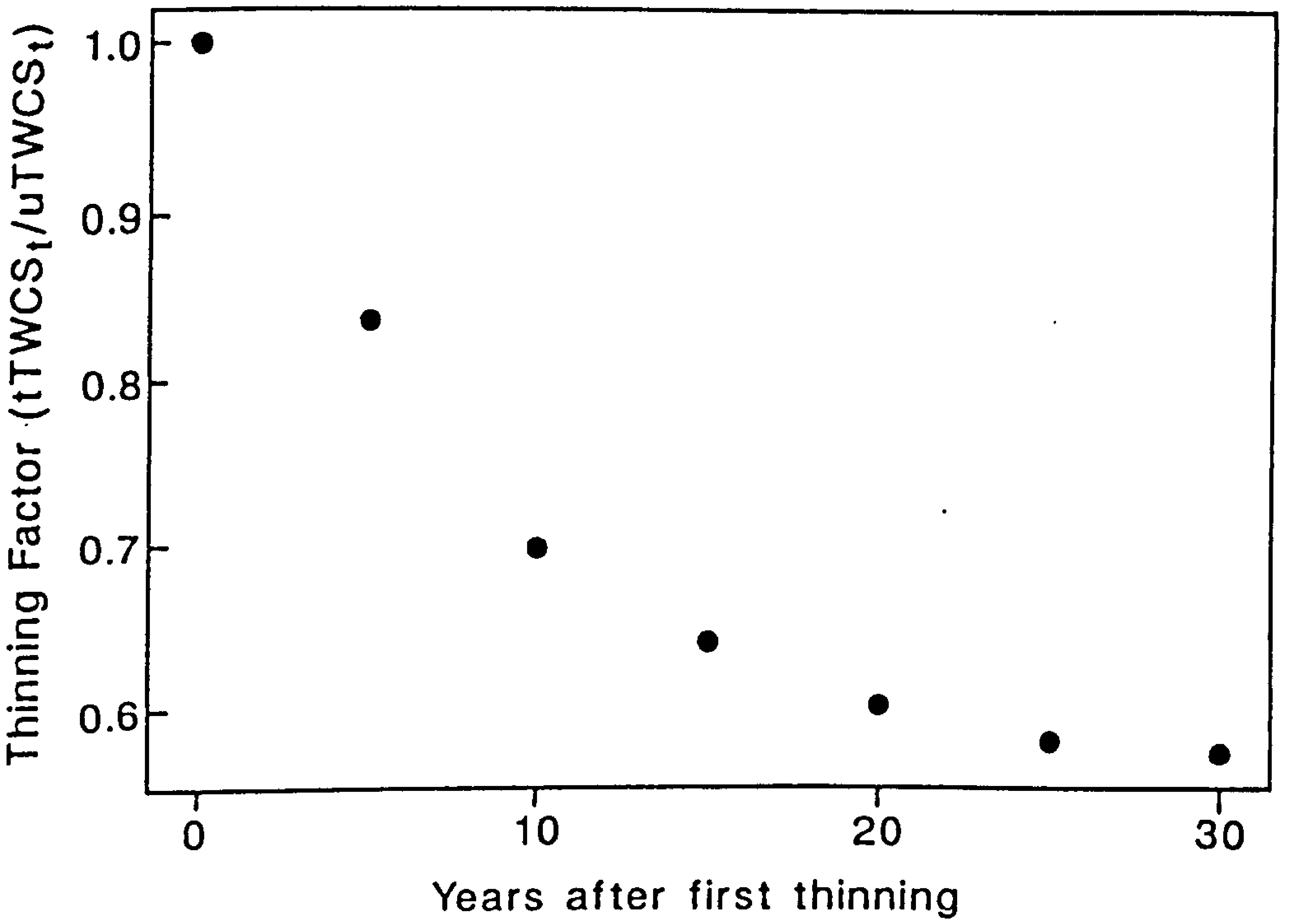
$R^2 = 82.1\%$ n = 4 Figures in brackets are t-statistics

The very low number of observations underpinning equation (8.18) means that our single explanatory variable is only significant at p = 0.10. Nevertheless the overall fit is satisfactory. TD1 can now be calculated for any given YC as per equation (8.19):

$$TD1_{BE,YC} = [0.47666 - (0.012861 * YC)] * F_{SS,YC} \qquad (8.19)$$

Dewar and Cannell (1992) do not report any information from which a thinning factor (TF_{BE}) might be estimated. However, we can obtain an estimate for this by examining the beech yield models of Edwards and Christie (1981). Figure 8.9 illustrates implicit TF_{BE} from data given in the latter.

Figure 8.9: Thinning factor for beech



Source: From data given in Edwards and Christie (1981).

Inspection of Figure 8.9 shows that TF_{BE} is very similar to TF_{SS} as detailed in Table 8.12. In both cases TF follows a roughly logarithmic pattern, falling rapidly once thinning commences to some fairly stable constant after about 30 years. We can therefore assume an approximate equality between these relationships as detailed in equation (8.20):

$$TF_{BE} = TF_{SS} = 1 - 0.1158 \ln t^* \tag{8.20}$$

where:

$$t^* = t - TD1$$

and

$$TF_{BE} = 1 \text{ for all } t^* < 0$$

We are now able to calculate total live wood tree carbon storage for thinned stands of beech ($tTWCS_{BE,YC}$) as per equation (8.21)

$$tTWCS_{BE,YC} = uTWCS_{BE,YC} * TF_{BE} \tag{8.21}$$

8.5 MODELLING CARBON LIBERATION FROM FELLING WASTE AND TIMBER PRODUCTS

An identical methodology was adopted with respect to modelling carbon liberation from both Sitka spruce and beech felling waste and timber products. As noted in table 8.4, end use clearly has a major impact upon overall carbon flux. To analyse this we need to consider the proportions of timber going to each end use. Table 8.14 provides such a breakdown of 1991/92 UK domestic production data divided into softwood and hardwood species.

Table 8.14: Softwood and hardwood end uses for UK domestic production 1991/92

Product	Softwood				Hardwood			
	'000 m^3	% of total	Modal liberation year (from felling)	95% carbon liberation (years from felling)	'000 m^3	% of total	Modal liberation year (from felling)	95% carbon liberation (years from felling)
Sawn logs	2925	49.292	70	150	558	49.512	150	300
Board	1154	19.447	15	40[1]	87	7.720	15	40
Paper	936	15.774	1	5	138	12.245	1	5
Mining	23	0.004	40	200	0	0.000	40	200
Fuel[2]	142	2.393	1	5	114	10.115	1	5
Other[2]	142	2.393	15	30	114	10.115	40	80
Bark	612	10.313	1	5	116	10.292	1	5
Total	5934	100.000	-	-	1127	100.000	-	-

Notes: 1. Based on this being almost exclusively particleboard as per statistics given in Forestry Commission (1992).
2. Based on assumption that roughly 50% of 'Other Industrial Wood' (FICGB, 1992) is fuelwood, as per statistics given in Forestry Commission (1992).

Sources: Carbon liberation dates from Cannell and Cape (1991) and Thompson and Matthews (1989a,b). Production data from FICGB (1992) and Forestry Commission (1992).

Examining table 8.14 indicates that, for all but the shortest lifespan products, carbon liberation appears to follow a roughly normal distribution. Conversely short lifetime products (those where virtually all carbon is liberated within five years of felling) have modal liberation during the year of felling after which liberation rates fall swiftly over time. Assuming a roughly straight line, downward sloping, liberation distribution for the latter and a normal distribution centred upon the modes listed in table 8.14 for all other products, we obtain the product specific carbon liberation schedules illustrated in figure 8.10 for Sitka spruce and figure 8.11 for beech. These are expressed as a proportion of the total amount of carbon stored in wood by 1 ha Sitka spruce during a full rotation.

Considering figure 8.10, panels (a) to (e) show carbon liberation distributions for Sitka spruce products and waste categorised according to longevity. Panel (f) sums all these to produce an overall liberation distribution. This shows that liberation is highest in the felling year and then falls rapidly to some low positive amount which then gradually declines over an extended period. A number of statistical models were fitted to this data including exponential and logarithmic functional forms. The optimal model is reported in equation (8.22) with predictions being illustrated in panel (g) of figure 8.10.

$$\mathrm{SUMLIBSS} = \underset{(6.30)}{0.0017146} + \underset{(36.53)}{0.110363}\ \mathrm{ETRENDSS} \qquad (8.22)$$

where

SUMLIBSS = sum of annual carbon liberation from all products and waste as a proportion of total carbon sequestration in wood from one rotation of Sitka spruce

ETRENDSS = $1/(1+t')$ where $t' = 0$ at felling and maximum $t' = 200$

$R^2 = 87.0\%$ $n = 201$ Figures in brackets are t-values.

Our TREND variable provides a good fit to the carbon liberation data as illustrated by the similarity between actual and predicted sum liberation shown respectively in panels (f) and (g) of figure 8.10. Equation (8.22) implies that all carbon stored by a Sitka spruce rotation will be liberated by $t' = 200$, after which we constrain SUMLIBSS to zero.

Figure 8.10: Annual carbon liberation distributions for products and waste expressed as a proportion of total carbon sequestration in wood from one rotation of Sitka spruce.

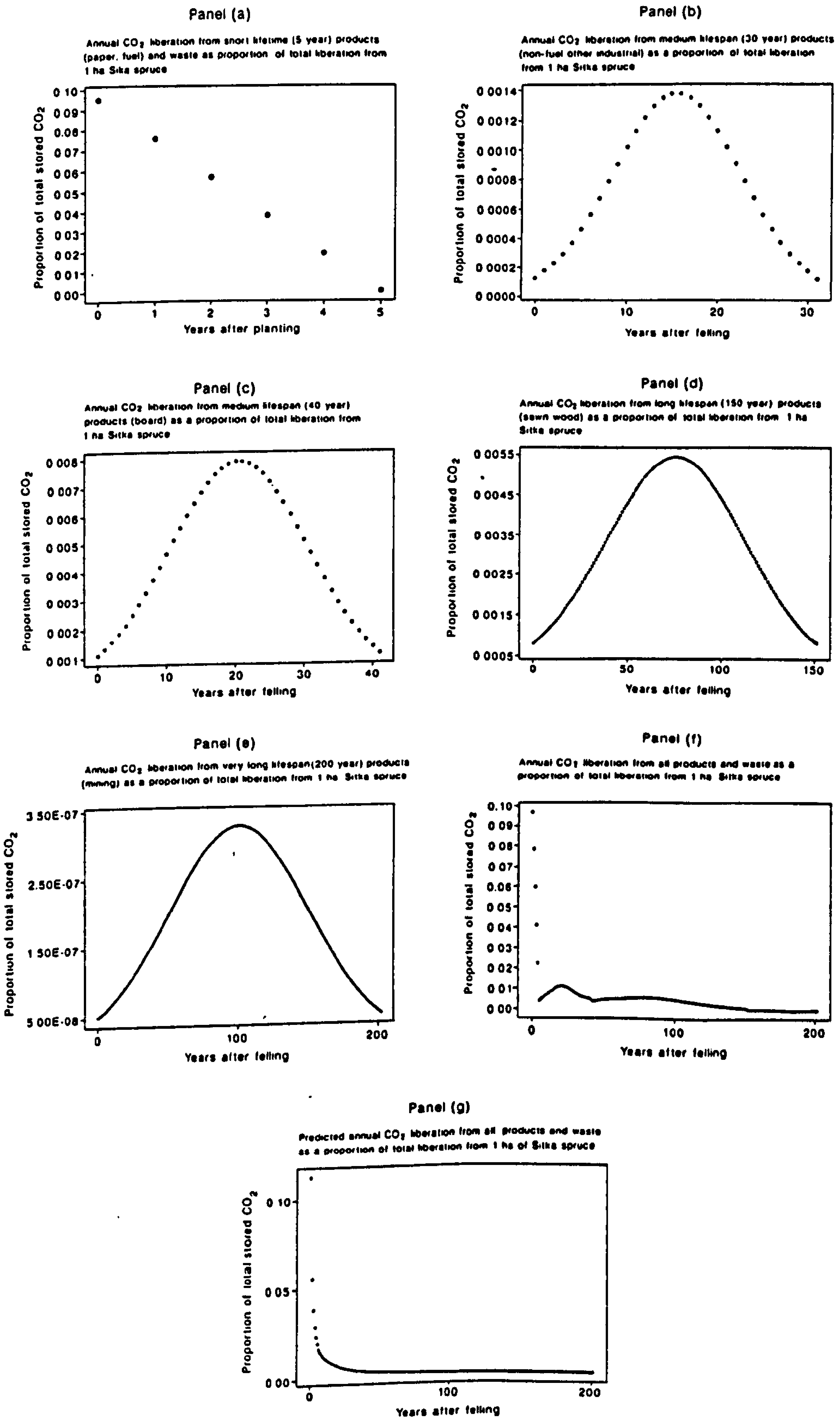
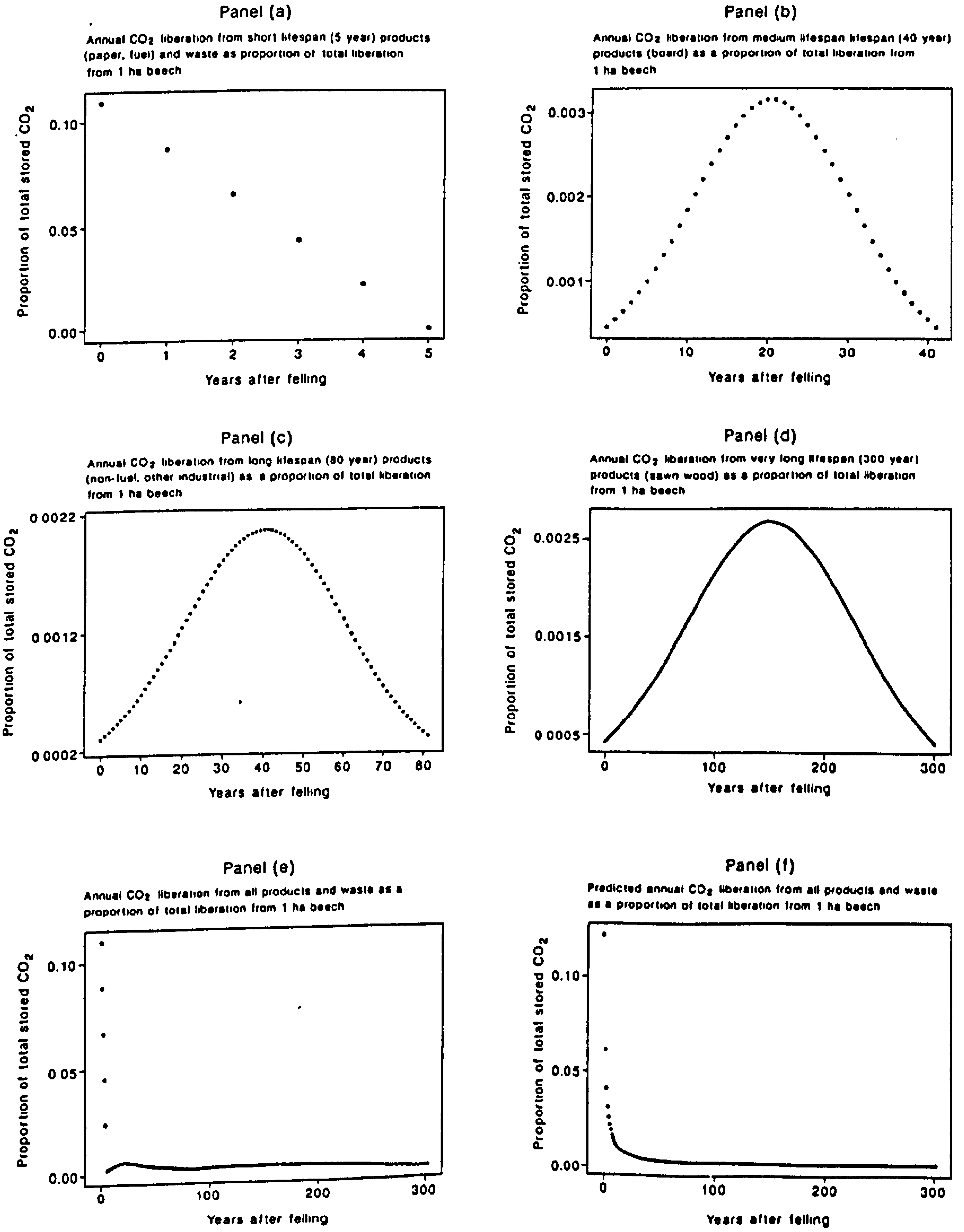


Figure 8.11: Annual carbon liberation distributions for products and waste expressed as a proportion of total carbon sequestration in wood from one rotation of beech



Turning to consider figure 8.11, panels (a) to (d) detail individual product carbon liberation distributions, while panel (e) illustrates their sum. Again this was modelled using a variety of approaches and functional forms with the best model being reported in equation (8.23):

$$\underset{}{\text{SUMLIBBE}} = \underset{(4.01)}{0.0007818} + \underset{(45.97)}{0.121461}\ \text{ETRENDBE} \tag{8.23}$$

where

SUMLIBBE = sum of annual carbon liberation from all products and waste as a proportion of total carbon sequestration in wood from one rotation of beech

ETRENDBE = 1/(1+t') where t' = 0 at felling and maximum t' = 300

$R^2 = 87.6\%$ n = 301 Figures in brackets are t-values

Equation (8.23) for beech adopts an identical form and explanatory variable as used for Sitka spruce in equation (8.22). A similar high degree of fit is achieved, illustrated by comparing actual and predicted liberation in panels (e) and (f) respectively of figure 8.11. Equation (8.23) implies that all carbon stored by a rotation of beech will be liberated by t' = 300 after which we constrain SUMLIBBE to zero.

8.6 MODELLING CARBON STORAGE AND LOSS FROM SOILS

Examining table 8.9 it is tempting to conclude that we should model individual soil category carbon changes including some element for altitude. Indeed the spatial capabilities afforded by GIS simplifies and invites such analysis. However, we are painfully aware of the paucity of data which underpins table 8.9 and of the numerous complications (such as the implications of replanting) which have yet to be quantified. We therefore adopt a simplified and conservative approach to modelling soil carbon flux along the lines of Sampson (1992), Dewar and Cannell (1992) and Matthews (1993) all of whom assume a constant, smooth and marginally diminishing carbon flux path for all soils.

Erring on the conservative side, table 8.9 supports a net long term increase in soil carbon equilibrium levels for non-peaty soils at a range of altitudes of about 50 tC/ha. For peat soils a net long term loss of some 750 tC/ha seems defencible. Following our literature review we know that for both peat and non-peat soils the rate of carbon flux will be highest immediately after felling and decline such that 95% of soil carbon change will have been achieved after roughly 200 years.

Equation (8.24) calculates the proportion of the total change in soil carbon ($PROPT\Delta SC_t$) which will have been achieved in any year t where t = 0 at planting. Notice that $PROPT\Delta SC_t = 1.00$ when t = 263 (after which it is constrained to equal 1.00 throughout the remainder of the period under analysis).

$$PROPT\Delta SC_t = 0.1793022 \ln TIME1 \qquad (8.24)$$

where

$TIME1 = t + 1$ where t = 0 at planting.

Equation (8.24) implies the necessary diminishing marginal rate of soil carbon change, values for which can be obtained by simple, one-period differencing. Multiplying these annual rates of change by the total change (50 tC/ha for non-peat soils and -750 tC/ha for peat soils) gives the annual soil carbon gains and losses.

8.7 RESULTS

8.7.1 NET CARBON STORAGE IN LIVE WOOD, PRODUCTS AND WASTE

The carbon storage and liberation equations reported for Sitka spruce and beech in sections 8.4.1 and 8.4.2 respectively were operationalised through a custom written fortran program which is reported with sample output in Appendix A6.2. This program yielded estimates of carbon sequestration value for the range of discount rates (both exponential and hyperbolic) and yield classes considered in this study. For each discount rate/yield class combination, three net carbon sequestration values were calculated: (i) the net present value of the initial optimal rotation; (ii) the net present value of a perpetual series of optimal rotations, and; (iii) the annuity equivalent of the latter. Appendix A6.2 reports full results of all these analyses for all three measures. For brevity, here we report just the first of these measures for Sitka spruce (see table 8.15) and beech (see table 8.16).

Table 8.15: NPV of net carbon flux (sequestration in live wood and liberation from products and waste) for an optimal rotation of conifer (Sitka spruce). Excludes all other externalities. Various yield classes and exponential and hyperbolic discount rates. Social values (£; 1990 prices).

r	YC4	YC6	YC8	YC10	YC12	YC14	YC16	YC18	YC20	YC22	YC24	YC26
1.5%	811.35	1165.67	1491.21	1815.01	2121.71	2414.74	2692.33	3001.75	3307.78	3608.75	3901.60	4228.45
2%	698.90	1006.52	1289.94	1570.32	1837.16	2089.14	2364.22	2634.23	2897.09	3151.26	3404.42	3651.99
3%	535.89	773.87	1005.20	1208.46	1415.17	1629.19	1815.88	2014.91	2198.56	2390.57	2566.79	2780.69
5%	342.45	495.55	643.20	784.73	916.29	1035.33	1160.39	1277.68	1393.39	1503.10	1625.63	1761.10
6%	283.89	411.26	534.92	652.61	761.24	859.49	963.10	1060.26	1155.64	1253.36	1367.30	1465.69
6% hyp.	439.77	636.77	825.37	1002.61	1161.13	1298.09	1441.40	1570.43	1704.97	1840.84	2008.19	2159.83

Table 8.16: NPV of net carbon flux (sequestration in live wood and liberation from products and waste) for an optimal rotation of broadleaf (beech). Excludes all other externalities. Various yield classes and exponential and hyperbolic discount rates. Social values (£; 1990 prices).

r	YC2	YC4	YC6	YC8	YC10	YC12
1.5%	886.40	1672.79	2400.93	3058.98	3690.33	4325.52
2%	706.48	1331.65	1888.62	2420.52	2941.13	3437.46
3%	466.41	875.00	1245.67	1606.50	1923.83	2261.71
5%	241.62	454.12	648.64	829.58	1003.34	1178.15
6%	186.28	348.89	496.74	638.08	775.31	907.36
6% hyp	371.64	665.73	914.48	1156.26	1390.22	1639.89

Considering tables 8.15 and 8.16 we can see that both yield class and discount rate have highly significant impacts upon net carbon sequestration values. These relationships allow us to estimate a series of linear regression equations where, for each specified discount rate, net sequestration value is related to yield class. This allows us to relate our carbon sequestration values directly to the yield class images created in Chapter 7 thereby producing maps of such values covering the entire extent of Wales. Such regression equations were estimated for both net present value and annuity sums for both species. The data for such regressions was taken from the net present value results detailed in tables 8.15 and 8.16 and from the annuity results reported in Appendix 6.2. Full results of this analysis are also given in Appendix 6.2 from which equations for net present value sums are reproduced as tables 8.17 (for Sitka spruce) and 8.18 (for beech) below.

Applying the various regression equations given in tables 8.18 and 8.19 (and the annuity equations detailed in Appendix 6.2) to the Sitka spruce and beech yield class maps estimated in Chapter 7 allows us to create images of net carbon sequestration values across Wales. These were created for both species and all discount rate combinations. Figures 8.12 and 8.13 show respectively the net present value (first optimal rotation) and annuity images for Sitka spruce using a 3% exponential discount rate. Similarly figures 8.14 and 8.15 show net present value and annuity images for beech, again using a 3% discount rate.

Table 8.17: NPV of carbon in live wood, waste and products from an optimal rotation of Sitka spruce: linear predictive equations with YC as the single explanatory variable (various discount rates).

Discount rate	Intercept (t-value)	Slope (t-value)	R^2 (adj)
1.5%	254.32 (14.62)	152.825 (145.11)	99.9
3%	187.70 (9.90)	100.460 (87.48)	99.9
6%	106.77 (9.06)	52.7081 (73.89)	99.8
6% hyperbolic	206.48 (8.47)	75.620 (51.24)	99.6

Table 8.18: NPV of carbon in live wood, waste and products from an optimal rotation of beech: linear predictive equations with YC as the single explanatory variable (various discount rates).

Discount rate	Intercept (t-value)	Slope (t-value)	R^2 (adj)
1.5%	281.86 (4.68)	341.518 (44.20)	99.7
3%	148.14 (4.92)	178.340 (46.18)	99.8
6%	56.18 (5.54)	71.800 (55.19)	99.8
6% hyperbolic	147.39 (8.25)	125.093 (54.51)	99.8

The images detailed in figures 8.12 to 8.15 strongly reflect the tree growth pattern analysed in Chapter 7 and consequently echo the environmental determinants of such growth. Given the caveat that we are for the moment ignoring soil carbon flux it would appear that net sequestration values are highest in lowland and sheltered areas where yield class is elevated.

Figure 8.12: Net present value (£/ha) of net carbon storage in live wood, products and waste from an optimal first rotation of Sitka spruce: 3% discount rate (image SS3CNPV)

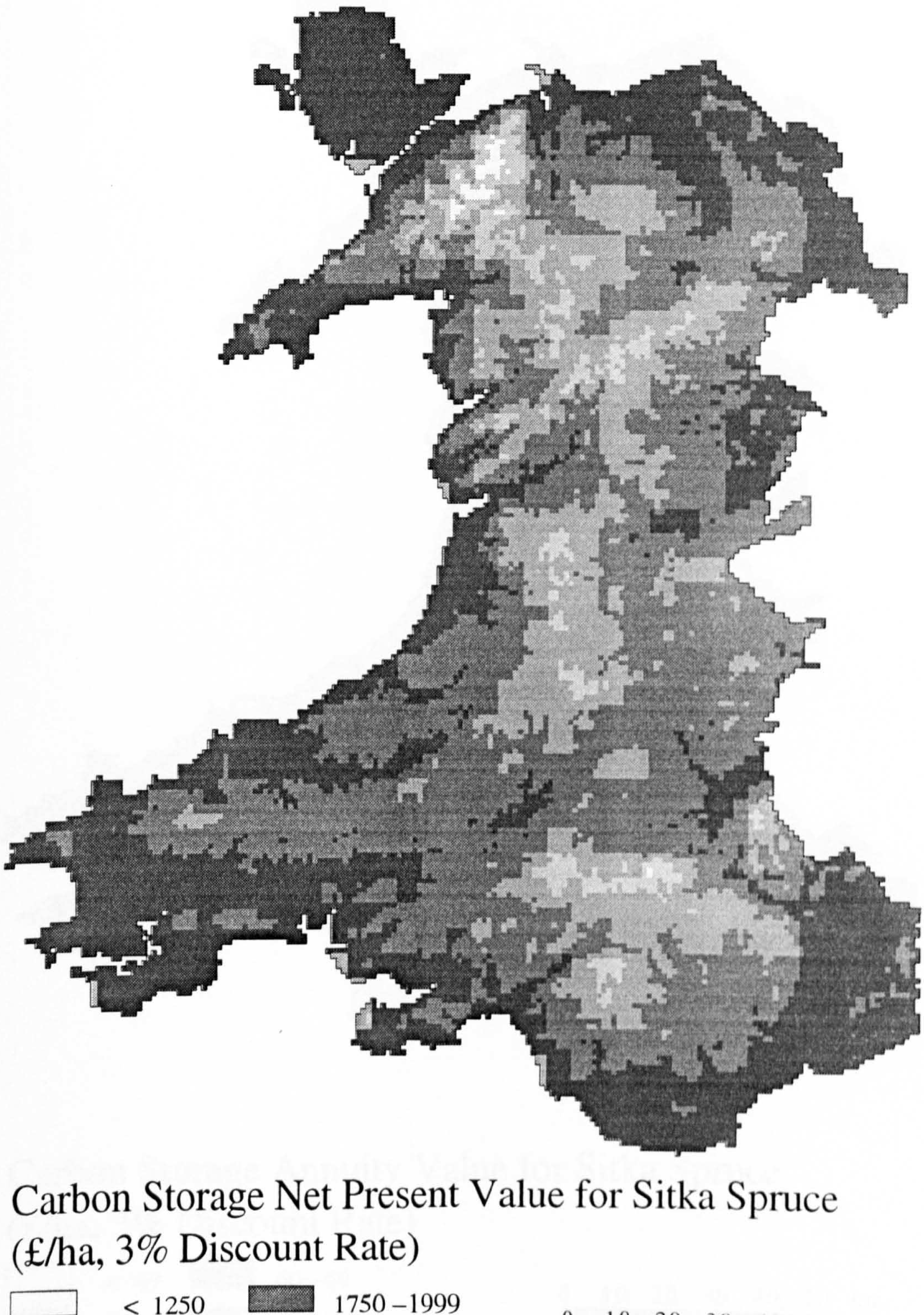


Figure 8.13: Annuity value (£/ha) of net carbon storage in Sitka spruce live wood, products and waste: 3% discount rate (image SS3CANN)

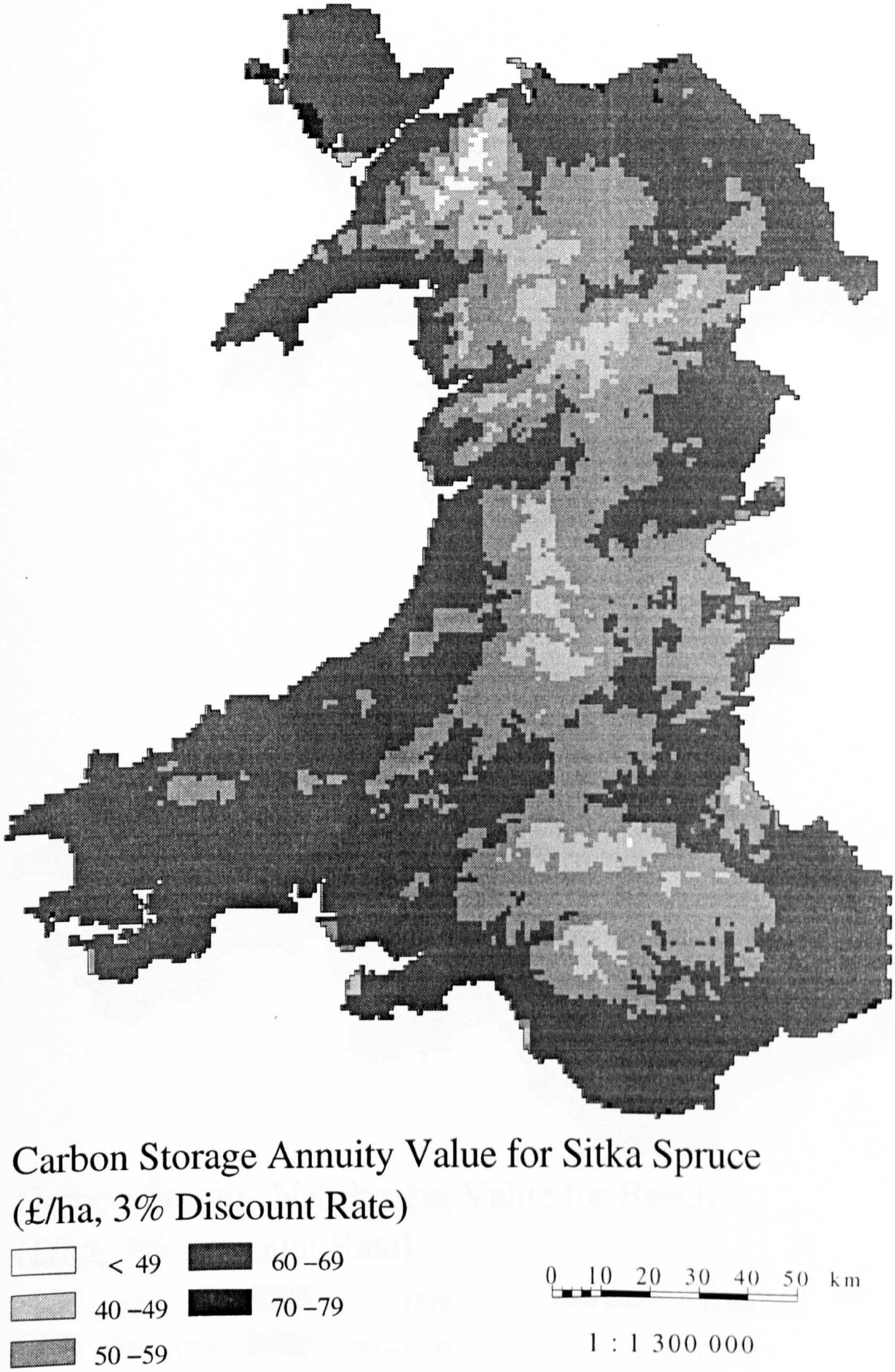
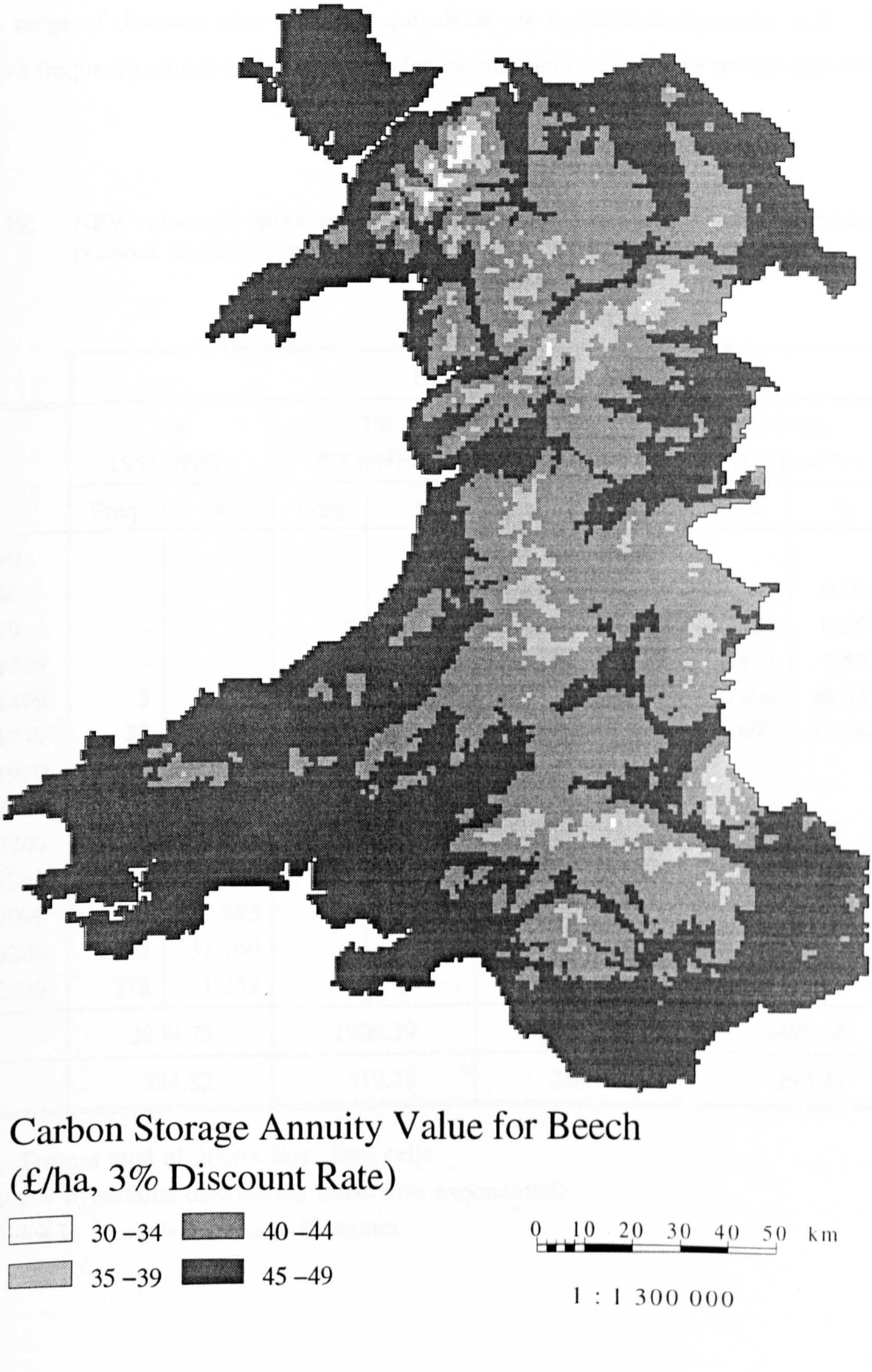


Figure 8.14: Net present value (£/ha) of net carbon storage in live wood, products and waste from an optimal first rotation of beech: 3% discount rate (image BE3CNPV)

Figure 8.15: Annuity value (£/ha) of net carbon storage in beech live wood, products and waste: 3% discount rate (image BE3CANN)



Figures 8.12 to 8.15 are all calculated holding discount rate constant at 3%. Tables 8.19 and 8.20 relax this restriction and compare the net present value of net carbon storage across a range of discount rates (annuity equivalents are reported in Appendix 6.2). The tables give frequency counts and percentages for the number of 1km^2 cells within each value band.

Table 8.19: NPV values for Sitka spruce carbon flux for live wood, waste and products (various discount rates)

NPV (£/ha)	Discount rate: 1% (SS1cNPV)		3% (SS3cNPV)		6% (SS6cNPV)		6% hyp (SS6HcNPV)	
	Freq[1]	%	Freq	%	Freq	%	Freq	%
250-499	-	-	-	-	1	0.005	-	-
500-749	-	-	-	-	228	1.109	1	0.005
750-999	-	-	5	0.024	8042	39.109	53	0.258
1000-1249	-	-	50	0.243	12292	59.777	1403	6.823
1250-1499	5	0.024	624	3.035	-	-	7409	36.031
1500-1749	27	0.131	3621	17.609	-	-	11697	56.884
1750-1999	71	0.345	8648	42.056	-	-	-	-
2000-2249	571	2.777	7615	37.033	-	-	-	-
2250-2749	2036	9.901	-	-	-	-	-	-
2500-2749	3561	17.318	-	-	-	-	-	-
2750-2999	6371	30.983	-	-	-	-	-	-
3000-3249	7643	37.169	-	-	-	-	-	-
3250-3499	278	1.352	-	-	-	-	-	-
Mean	2859.75		1900.39		1005.36		1495.68	
s.d.	384.82		319.28		266.81		293.42	

Notes: 1. From a total of 20563 1km^2 land cells
hyp = hyperbolic discounting (otherwise exponential)
Items in brackets are image filenames

Table 8.20: NPV values for beech carbon flux for live wood, waste and products (various discount rates)

NPV (£/ha)	Discount rate 1% (BE1cNPV)		3% (BE3cNPV)		6% (BE6cNPV)		6% hyp (BE6HcNPV)	
	Freq[1]	%	Freq	%	Freq	%	Freq	%
250-499	-	-	-	-	161	0.783	-	-
500-749	-	-	-	-	20402	99.217	-	-
750-999	-	-	-	-	-	-	1493	7.261
1000-1249	-	-	159	0.773	-	-	19070	92.739
1250-1499	-	-	7809	37.976	-	-	-	-
1500-1749	-	-	12595	61.251	-	-	-	-
1750-1999	1	0.005	-	-	-	-	-	-
2000-2249	41	0.200	-	-	-	-	-	-
2250-2499	387	1.882	-	-	-	-	-	-
2500-2749	4057	19.730	-	-	-	-	-	-
2750-2999	8457	41.127	-	-	-	-	-	-
3000-3249	7620	37.057	-	-	-	-	-	-
Mean	2907.06		1518.99		608.08		1108.96	
s.d.	320.42		273.61		236.07		260.33	

Notes: 1. From a total of 20563 1km² land cells.
hyp = hyperbolic discounting (otherwise exponential)
Items in brackets are image filenames.

Analysis of tables 8.19 and 8.20 shows that both the choice of discount rate and choice of species has a substantial impact upon net carbon storage values. Of particular interest is the finding that the more elongated growth period of beech results in lower discounted values of carbon sequestration. However, as expected, this divergence of values between species falls as does the discount rate.

8.7.2 EXTENDING THE ANALYSIS TO INCLUDE SOIL CARBON FLUX

Equation (8.24) defines the total proportion of soil carbon flux (sequestration or liberation) achieved in any year t for any tree species (see previous discussion). A worksheet was set up and this equation used to define the proportion of soil carbon flux achieved in each year following initial planting[32]. This was then differenced to calculate the marginal proportion change in any year t. The actual marginal change in soil carbon was then obtained by multiplying the total change over the full 1000 year period under analysis (50 tC/ha for non-peaty soils; -750 tC/ha for peaty soils) by the marginal proportion change in each year.

This annual soil carbon gain or loss was then valued using the Fankhauser values as discussed previously. These values were then discounted at various rates and NPV (perpetuity)[33] sums and annuities equivalents calculated as detailed in tables 8.21 and 8.22 respectively.

Table 8.21: NPV (perpetuity)[1] sums for soil carbon flux: all tree species (£/ha).

Soil type	Discount rate			
	1.5% (s1NPV)[2]	3% (s3NPV)	6% (s6NPV)	6% hyperbolic (s6hNPV)
Non-peaty	742.91	601.23	476.08	584.99
Peaty	-11144.00	-9018.40	-7141.30	-8774.80

Notes: 1. Calculated for t = 0 to 999
2. Figures in brackets are image filenames.

GIS images of soil carbon flux values were created by applying the values given in tables 8.21 and 8.22 to our LandIS soil map. We therefore obtain four NPV and four annuity soil carbon flux images (one for each discount rate). Figure 8.16 illustrates image s3NPV.

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[32]See worksheet SOILCARB.MTW and log file AUG18A.LIS.

[33]Given that soil carbon change is a slow process, taking many rotations to complete, calculation of first rotation NPV sums is of less interest than in our analysis of tree carbon fixing values.

Table 8.22: Annuity sums[1] for soil carbon flux: all tree species (£/ha).

Soil type	Discount rate			
	1.5% (s1ANN)[2]	3% (s3ANN)	6% (s6ANN)	6% hyperbolic (s6hANN)
Non-peaty	11.14	18.04	28.56	35.68
Peaty	-167.16	-270.55	-428.48	-535.26

Notes: 1. Calculated for t = 0 to 999
2. Figures in brackets are image filenames.

Figure 8.16 reflects the concentration of peaty soils within upland areas[34], showing the very large carbon liberation costs caused by planting on such soils. However, peaty soils account for just 489 of the 20563 1km^2 land cells in our coverage of Wales[35].

In order to assess the full impact of planting upon carbon flux the values for net storage in live wood, products and waste detailed in Appendix 6.2 (of which tables 8.19 and 8.20 are an extract) were extended to include the soil carbon values itemised in tables 8.21 and 8.22[36]. The resulting net total carbon storage values images are detailed in Appendix 6.2 (which reports frequency tables for all generated images). Here the frequency tables for Sitka spruce NPV sums at all considered discount rates are reported as table 8.23.

The most striking feature of table 8.23 is the highly bipolar distribution of results. Planting upon peat soils causes vary large soil carbon losses which overwhelm any values generated by storage in live wood. However, elsewhere the value of carbon storage is both positive and substantial. Given the nature of this distribution, mean values and variance measures are somewhat meaningless, however the spatial distribution of values is well illustrated in figure 8.17 which shows the NPV values for net carbon flux generated by Sitka spruce when assessed using a 3% discount rate. For comparison, figure 8.18 illustrates the annuity equivalent of this image, frequency tables being reported in Appendix 6.2.

[34]A notable exception is the lowland Borth bog clearly seen on the mid-western coast of figure 8.a

[35]Note that the "blocky" nature of figure 8.16 is due to the 5km^2 resolution of the LandIS soil map upon which it is based.

[36]This operation was achieved by use of the *Overlay* command discussed previously.

Figure 8.16: Soil carbon flux NPV map, discount rate = 3% (image S3NPV)

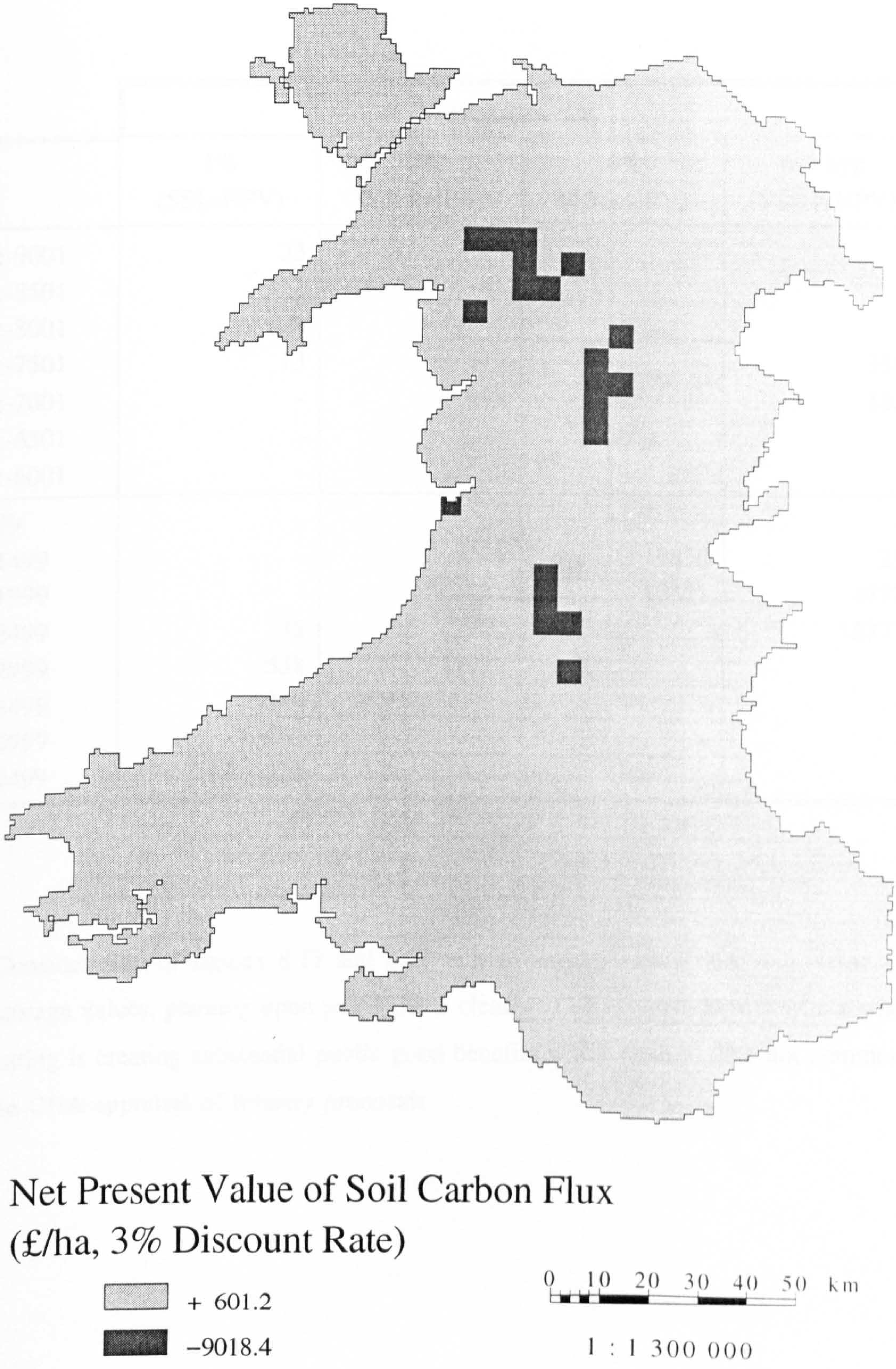

Table 8.23: Frequency table: NPV sums for net carbon flux (live wood, waste, products and soils): Sitka spruce (£/ha, 1990)

NPV (£/ha)	Discount rate 1% (SS1xNPV)	3% (SS3xNPV)	6% (SS6xNPV)	6% hyp (SS6HxNPV)
-9500:-9001	33	-	-	-
-9000:-8501	438	-	-	-
-8500:-8001	5	-	-	-
-8000:-7501	13	177	-	356
-7500:-7001	-	298	-	133
-7000:-6501	-	14	-	-
-6500:-6001	-	-	489	-
500:999	-	-	3	-
1000:1499	-	1	9650	25
1500:1999	-	181	10421	4772
2000:2499	32	7907	-	15277
2500:2999	538	11985	-	-
3000:3499	5349	-	-	-
3500:3999	13933	-	-	-
4000:4499	222	-	-	-

Consideration of figures 8.17 and 8.18 tells a common story that, with respect to carbon storage values, planting upon peat soils is clearly to be avoided. However, elsewhere such planting is creating substantial public good benefits which have to date not commonly figured in CBA appraisal of forestry proposals.

Figure 8.17: NPV sums (£/ha) for net carbon flux (live wood, products, waste and soils): Sitka spruce (image SS3XNPV)

Figure 8.18: Annuity sums (£/ha) for net carbon flux (live wood, products, waste and soils): Sitka spruce (image SS3XANN)

8.8 SUMMARY

The objective of this chapter was to produce maps of the value of net carbon flux induced by planting trees in locations across Wales. This was achieved by first reviewing the existing literature regarding the value of carbon sequestration or liberation per se. Here we concluded that the work of Fankhauser represents the current state of the art and duly adopted his valuations used later in the chapter. Our second and principle objective was to construct, for both of the tree species under investigation, models of the quantity of carbon sequestered, or liberated from three sources: the growth of live wood; changes in the carbon content of woodland soils and; carbon liberation from felling waste and timber products. These models were necessarily dynamic and were run over a highly extended period. While the live wood carbon sequestration and product liberation models were related to the YC predictions detailed in chapter 7, the soil carbon flux models relied upon data given int he Land IS database. In both cases these allowed the production of spatially differentiated estimates of carbon flux which were then converted into GIS-based valuation maps using the Fankhauser values mentioned above. Overlay of these maps permitted the construction of a net carbon flux valuation map for both of the species under consideration. Such maps are directly compatible with those previously estimated for woodland recreation and timber production values.

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SECTION B: AGRICULTURE

Chapter 9: Modelling Agricultural Output Values

9.1: INTRODUCTION

Having concluded our assessment of the monetary value of land under forestry we now turn to consider the prime opportunity cost of such a decision, namely the value of the major land use in Wales; agriculture. One approach to such evaluation would be to use land prices. However, farmers are notoriously unwilling to abandon their profession and, given that it is an explicit objective of the Common Agricultural Policy (CAP) to support farming communities, it seems infeasible that UK policy (which has to be framed within the CAP) would advocate the widespread buying up of farmland for conversion to forestry or other 'environmental' schemes[1]. Rather then it seems more sensible to assess existing agricultural incomes and compare with those obtainable under forestry, accepting that farmers are likely to, at most, undertake partial rather than wholesale conversions from existing outputs into woodland. This chapter presents models of net agricultural income and its social (shadow price) equivalent. As before a GIS-based approach is used linking such values to full map coverages of environmental variables for the entire study area. This permits subsequent comparison of total woodland values with those for agriculture (see Chapter 10).

9.1.1: OVERVIEW OF CHAPTER

The following section (9.2) presents the necessary policy background. This establishes the broad economic case for transfers out of conventional agriculture and into alternative land-uses and overviews the theoretical and methodological basis of our analysis. The data used in this study is reviewed in section 9.3 while the following section details a cluster analysis of this data dividing farm records into relatively homogeneous agricultural sectors. This analysis identifies two sectors as dominating Welsh agriculture: the first containing farms which derive the majority of their income from dairying, while the second contains farms which mainly specialise in sheep production.

As with our study of woodland, we are concerned with both the market and social

[1]Indeed in debating this notion, Colman (1991) explicitly notes that, at best, such land purchase schemes will be on a minor scale.

values of agriculture and to facilitate assessment of the latter section 9.5 presents a shadow pricing exercise for the agricultural outputs concerned. With the necessary farm data assembled, in section 9.6 we turn our attention to the environmental characteristics of individual farms and, as for our study of timber output values, conduct a principle components analysis (PCA) of environmental variables. Both PCA and raw variables are used in subsequent models of output values for mainly sheep and mainly milk farms (sections 9.7 and 9.8 respectively). Maps of the market and social values of output predicted for both sectors are presented and discussed in section 9.9.

9.2: BACKGROUND

9.2.1: POLICY BACKGROUND IN THE UK

Government intervention within the British agricultural sector can be traced back to at least the Middle Ages (Ernle, 1919) and so it would be wrong to characterise farms as being purely subject to market forces prior to the UK's entry into the EC in 1973[2]. Nevertheless, the simultaneous entry into the Common Agricultural Policy (CAP) heralded one of the most fundamental changes in the organisation of agriculture in the entirety of Britain's peace-time history.

9.2.1.1: The CAP Support System

The policy principles of the CAP were laid down in 1958 as Article 39 of the foundation document of the EC, the Treaty of Rome (HMSO, 1962). This advocated a basically expansionist ideology enshrined in various potentially conflicting intentions to ensure: (i) producer efficiency; (ii) market stability; (iii) consumer equity, and; (iv) a 'fair' standard of living for farmers[3]. In considering the subsequent interpretation and implementation of these aims, commentators have highlighted both the post-war demand for greater food security and the fact that the CAP is a product of the Treaty of Rome and was therefore seen as a cornerstone of the underlying desire, particularly by the Commission of

[2]Market restrictions and intervention prior to 1973 are discussed in Bowers and Cheshire (1983); Blunden and Curry (1985); Robinson (1990); Smith (1990); Ritson (1991a) and Cobb (1993).

[3]Discussion of these aims is presented in Blunden and Curry (1985); Franklin (1988); Fearne (1991a) and Ritson (1991b).

the European Community (CEC), for greater political union between member states (Bowler, 1985; McInerney, 1986; Fennell, 1987).

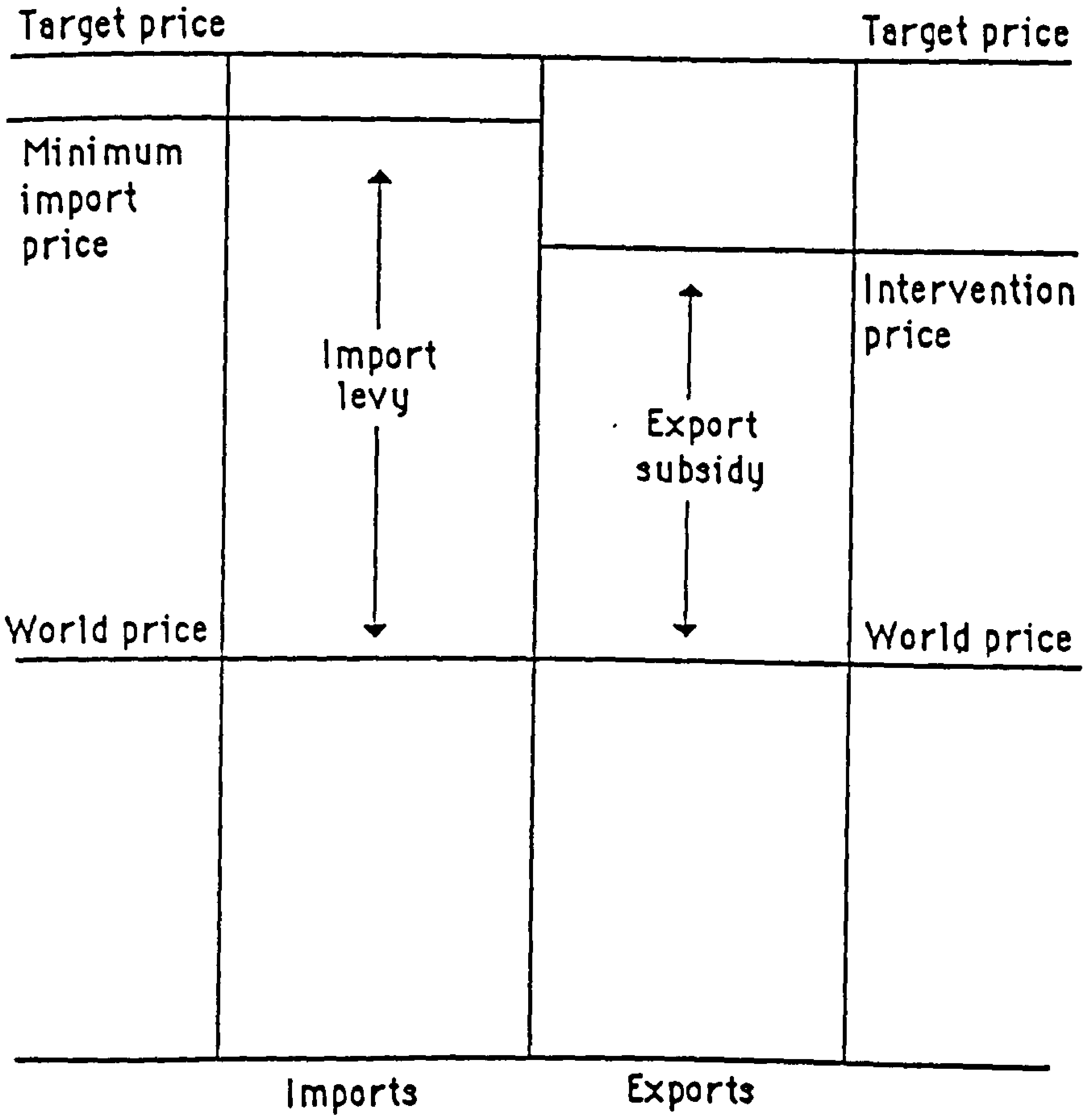
In practice a special section of the Community budget, usually known by its French acronym FEOGA, the European Agricultural Guidance and Guarantee Fund, was created to finance the expansion of EC agriculture. Rather than assistance being paid directly to farmers it was decided that each year the Council of Ministers would set a 'target price' for each commodity, usually significantly above the prevalent world price. This internal EC target price was principally maintained by imposing an import levy upon non-EC produce. However, while this was adequate for most goods where the EC was a net importer, if domestic supply exceeded demand then the possibility of surpluses depressing internal prices arose. To combat this a system of export subsidies was introduced payable where internal-EC prices fell below an 'intervention price' level set somewhere below the target price but about world price. Figure 9.1 illustrates the essentials of the support system.

An important complexity arises from the internal operation of the CAP in the absence of monetary union. Support prices are fixed in ECU and have to be translated into actual payments via national currencies. However, fluctuations in exchange rates could lead to substantial and quickly transmitted instability in producer prices. Therefore, for agricultural goods alone, EC member states were allowed to maintain prior exchange rates (known as 'green' currency) for converting CAP support prices into domestic prices. This system caused differences in realised support prices for the same commodity across countries and if left unchecked would lead to goods moving from low-price to high-price countries prior to their sale into intervention. Consequently a system of border taxes and subsidies (known as Monetary Compensation Amounts; MCA's) on intra-EC trade was also introduced (Fennell, 1987; Ritson, 1991a). The advent of the EU Single Market on January 1st 1993 swept away internal borders making MCA's unworkable. While a strong exchange rate mechanism (ERM) would have reduced many problems, the exit of Britain and Italy from the ERM on 16th September 1992 precluded this option and necessitated a compromise solution wherein green currencies now effectively 'float' with devaluation in the green pound occurring regularly (Neville and Mordaunt, 1993)[4].

[4]Between September 1992 and March 1993 the green pound was devalued eight times by a total of 23.3%.

Figure 9.1: Model of a typical CAP price support system

INSERT FIG. 1.1. CH. 1 OF RITSON AND HARVEY



Source: Ritson (1991a)

9.2.1.2: Operation of the CAP: Market failure

The UK's entry into the EC and CAP in 1973 coincided with the world commodity price boom which was primarily responsible for a substantial increase in agricultural prices, for which the CAP got much of the blame (Britton, 1990; Robinson, 1990; Hodge, 1990a; Ritson, 1991b). Food prices rose by 18% in 1974 and 24% the following year (Capstick, 1991). Indeed the retail food price index kept above that of other items for the remainder of the 1970's and first half of the 1980's (ibid), a trend echoed in the expansion of land prices during the period (Harvey, 1991a). During the mid 1970's the price guarantee system and worldwide price buoyancy resulted in increased agricultural stability and incomes (Blunden and Curry, 1985; Hill, 1990; Moyer and Josling, 1990) although this was bought at the cost of welfare losses to consumers and taxpayers. However, the obvious consequence of increased price subsidies was more production and with it higher support costs, which with sluggish growth in domestic demand (Harrison and Tranter, 1989; North, 1990), could only result in higher export subsidies and intervention storage costs (Blunden and Curry, 1985; Buckwell, 1989; Smith, 1990; Cobb, 1993). During the late 1970's and early 1980's the total budget costs of the CAP rose by around 25% per annum (Cobb, 1993) with FEOGA guarantee expenditure increasing from about ECU 2.5 billion in 1970 to nearly ECU 30 billion in 1988 (Moyer and Josling, 1990).

The price pressure of this level of support led to an increased misallocation of resources (Marsh and Swanney, 1980; Tarrant, 1980; Body, 1982; Buckwell et al., 1982; Hill, 1984)[5] and resultant inefficiencies which meant that as producer subsidy equivalents rose from about 30% to peak at over 60% in 1987 so the net economic loss (sum of producer and consumer welfare effects) of the CAP rose to exceed ECU 9 billion in 1986 (Josling, 1993). Despite widespread criticism, in practical terms little was done to alleviate a rapidly worsening situation. Many commentators both then and since have identified the decision-making framework as the principle cause of this policy response lag with particular criticism being aimed at the willingness of the Council of Ministers to avoid difficult decisions and put the short term concerns of their national agricultural constituencies before the long term need for budgetary prudence (Marsh and Swanney, 1980; Hill, 1984; Bowler, 1985; Fennel, 1987; Hodge, 1990b; Smith, 1990; Fearn, 1991b; Josling, 1993; Winters, 1993). The UK was by no means innocent of such prevarication, for example, the green pound was frequently devalued during this period thus raising MCA payments to UK farmers (Harris et al., 1983). In essence then, the CAP exhibited all the signs of a classic intervention failure (Hill, 1984).

9.2.1.3: The movement towards liberalisation and subsidisation of positive environmental externalities

Eventually the EC was forced to acknowledge that something had to be done about the spiralling CAP budget (CEC, 1985a). While thresholds upon guarantees had been

[5]EC subsidies and consequent increase in exports and depression of world prices also had major impacts upon non-EC countries and in particular the less-developed world (Anderson and Tyers, 1991). The economic consequences of this effect are considered in section 9.5.

introduced in 1982 (Cobb, 1993) the first substantial response came with the introduction of milk quotas (CEC, 1985b). While the Council of Ministers still provided a break upon reform (CEC, 1989; 1990a), nevertheless gradual reductions in support for milk (EEC, 1987) and cereals were introduced (CEC, 1987) and in real terms prices began to fall throughout the late 1980's (Moyer and Josling, 1990; Hubbard and Ritson, 1991). This coincided with a reduction in non-price support, for example UK grants dropped from almost £200m in 1983/84 to about £23m in 1988/89 with capital allowances being cut in 1986 (Cobb, 1993).

The severity of these real-price decreases meant that by 1990 the food price index had fallen below that of general prices (Capstick, 1991) and there was considerable evidence that relative agricultural incomes had retreated back to the levels of the early 1980's (Howarth, 1985; OECD, 1987; Hill, 1990; Moyer and Josling, 1990). Nevertheless, the induced rise in productivity and falls in demand (Capstick, 1991; CEC, 1992a) meant that in the 1990's the budgetary costs of the CAP have remained high and analyses show that the overproduction induced by the present system continues to constitute a clear economic loss (Morris, 1980; ABAE, 1985; Tyers and Anderson, 1987; Rosenblatt et al., 1988; Anderson and Tyers, 1991). One of the consequences of this situation is that, under present capitalization, far more EC land is being used for agriculture than is economically efficient, with estimates of surplus agricultural land in the UK ranging from 0.7 million to 5 million hectares (North, 1990; Potter et al., 1991; Harvey, 1991b)[6]. This observation has combined with longstanding but ongoing concerns regarding the negative environmental impacts of present land-use (NCC, 1977; Shoard, 1980; Body, 1982; Hodge, 1990a and c; MacKenzie, 1990; Whitby, 1991a and b) to lead many commentators to consider the possibility of reorientating support away from conventional production measures and towards a more holistic agri-environmental system where both food and amenity become recognised and remunerative farm outputs (Baldock and Conder, 1987; Bowers, 1987; Blunden and Curry, 1988; DoE, 1988; Potter, 1988 and 1990, RSPB, 1988; Hodge, 1990d; Neville-Rolfe, 1990; Cobb, 1993; Colman, 1993).

At the EC level the most profound response to these dual pressures of the need to reduce output and related subsidies while enhancing environmental values, was embodied in the so-called MacSharry Reforms (CEC, 1991). These proposed a substantial reduction in price support compensated for by direct payments to farmers conditional upon placing land

[6]This is a developing problem which may take up to 15 years to reach the higher estimates quoted here (see Harvey, 1991).

into non-productive 'set-aside' with further requirements to reduce negative environmental impacts. Although subsequently watered down, the principle of such reforms were accepted (CEC, 1992b and 1992c; Neville and Mordaunt, 1993); however, in practice set-aside has operated as a method of reducing output and budgetary costs rather than as an overtly environmental tool.

At the national level a number of UK policies have also addressed these joint aims including the Alternative Land Use and Rural Economy (ALURE) package (MAFF, 1987), the Premium Scheme (MAFF, 1990), and the Countryside Stewardship Scheme (MAFF, 1992) which arose from the Government White Paper "Our Common Inheritance" (H.M. Government, 1990). While these have been criticised with respect to the limited extent of funding for such schemes (Robinson, 1991; House of Lords, 1992; NFU, 1992), nevertheless these do mark a significant reorientation of UK agricultural policy and recognition of the symbiosis of land use and the environment which many now see as a permanent policy shift (Neville-Rolfe, 1990; Colman, 1991).

9.2.1.4: Conclusions: The potential for change

What this policy review clearly shows is the established potential for economic gains (both in the sphere of market efficiency and the provision of environmental benefits) from the reform of agricultural policy (Burrell, 1987; Tyers and Anderson, 1987; Rosenblatt et al., 1988; Anderson and Tyers, 1991). In particular there is the possibility of welfare improvements arising from inducing conversions out of conventional agriculture and into alternative land-use such as the woodland option considered in this study. However, while the possibility of creating positive social net benefits clearly exists, such transfers are unlikely to occur unless we also consider the consequent market value to producers. In subsequent sections we discuss approaches to the modelling of both the social and market values of agriculture so that such a comparative analysis can be undertaken.

9.2.2: MODELLING AGRICULTURAL VALUES: A BRIEF REVIEW

While early considerations of the theory of the firm tended to focus primarily upon the production function (e.g. Cobb and Douglas, 1928; Solow, 1956), the development of duality theory (Shephard, 1953; McFadden, 1966; Diewart, 1973 and 1974) has allowed a much richer specification of production relationships than those assumed in traditional Cobb-

Douglas or similar production functions[7]. While empirical analyses still frequently concentrate upon estimating production functions[8], now many studies make use of the methodological flexibility afforded by duality to estimate cost functions[9] and, in particular, profit functions[10]. It is this latter approach which is adopted by the UK study which most closely resembles the present research, namely the NERC/ESRC Land Use Modelling Programme (NELUP), currently ongoing at the University of Newcastle upon Tyne (O'Callaghan, 1992; 1995)[11].

Despite being developed in isolation[12], similarities between NELUP and our own agricultural modelling methodology (discussed in detail below) are striking. Both studies use a GIS to integrate the physical environment into a profit function analysis (Wadsworth, 1992; Moxey and Allanson, 1994; Moxey et al., 1995a; Watson and Wadsworth, 1996)[13]. Specifically NELUP combines hydrological (Dunn et al., 1992; Lunn et al., 1992; Adams et al., 1995) and ecological (Luff et al., 1992; Rushton et al., 1995) models with economic models (Moxey et al., 1995b) for the case study area, namely the Tyne River catchment. The large scale resources and analytical expertise applied to this programme have produced a very high quality model capable of detailed analysis of issues such as the prediction of land use (Moxey and Allanson, 1994; Verdiesen and Moxey, 1994; Haslam and Newson, 1995; McClean et al., 1995a), landscape assessment (Smith et al., 1992; Wadsworth and O'Callaghan, 1995), ecological predictions (Rushton, 1992; Eyre, 1992), estimation of

[7]Introductions to duality theory are presented (in ascending order of complexity) by Gravelle and Rees (1981); Kreps (1990); Varian (1984); Antle and McGuckin (1993); Binswanger (1975); Thirtle (1996a and b) and Deaton and Muellbauer (1980). The most thorough coverage is provided in the book edited by Fuss and McFadden (1978) and in particular the chapters by McFadden (1978a and b), Hanoch (1978), Lau (1978) and Fuss et al. (1978).

[8]Good introductions to the estimation of agricultural production functions are provided by Yotopoulos and Nugent (1976) and Hayami and Ruttan (1985). Other agricultural examples include: Kaneda (1982); Just et al. (1983); Burton (1992); Coyle (1992); Neff et al. (1993); Mainland and Dryburgh (1994); Howitt (1995); and Battese et al. (1996).

[9]Agricultural examples of cost function estimations include: Binswanger (1974); Lopez (1980); McKay et al. (1980); Ball and Chambers (1982); Ray (1982); Hanley and Lingard (1987); Shoemaker (1988); Glass and McKillop (1989); Clark and Youngblood (1992); and Pope and Chavas (1994).

[10]Agricultural examples of profit function estimations include: Lau and Yotopoulos (1972); Sidhu and Baanante (1981); McKay et al. (1982); Weaver (1983); Lopez (1985); Wall and Fisher (1987); Ball (1988); Burrell (1989); Chambers and Pope (1994).

[11]Another important ongoing study is the Land Use Allocation Model (Harvey et al., 1986; Jones et al., 1995) currently under development at the University of Reading. This linear programming model also uses FBS data although, as per the NELUP model this is aggregate rather than farm level. Consequently many of our comments regarding NELUP could also be applied to the LUAM model.

[12]First contacts with the NELUP team were made in 1995.

[13]Moxey (1996) notes the recent growth of interest in applying GIS to the field of agricultural economics.

production coefficients (Moxey and Tiffin, 1994), etc. Therefore the NELUP model does have significant areas of advantage over our own approach. Nevertheless, there are at least three important areas where our model is likely to be superior. Firstly, the NELUP team model lacks information on alternatives to agriculture such as the woodland option focused upon here. A second issue has been well documented by the NELUP team themselves, namely possible inaccuracies within certain aspects of the data underpinning the ecological elements of NELUP. The initial model, which utilised the Institute of Terrestrial Ecology (ITE) land classification system (Bunce et al., 1981), proved relatively poor at predicting variation in land use (McClean and Moxey, 1993). Indeed the same researchers recognise the superiority of the Macauley Land Use Research Institute (MLURI) land capability classification system (Bibby et al., 1991) which is similar to the SSLRC approach used in this study. NELUP currently bases its ecological model upon the remotely sensed ITE Land Cover Map of Great Britain (Fuller et al., 1994). The accuracy of this data is variable, being dependent upon the ability of Landsat data to correctly discriminate between land uses. Work by NELUP researchers shows that the largest errors occur with respect to upland areas (Cherill et al., 1995; McClean et al., 1995b) while ongoing work by Brainard (*pers. comm.*)[14] suggests that this problem may also apply to the data on woodlands. Given that our study specifically focusses upon transfers into woodland within a generally upland area this must somewhat compromise the application of a NELUP-style ecological model to the Welsh study area.

Thirdly, and most importantly, unlike our own study, the NELUP model does not have access to farm-level data[15] but has instead to depend upon aggregated Parish level agricultural census information collected by the Farm Business Survey (Allenson et al., 1992). This is a substantial drawback as it precludes the possibility of relating the input-output situation of a particular farm to the characteristics of its specific environment.

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[14] This work, in collaboration with Andrew Lovett and the author, extends the benefit transfer model presented earlier in this study. As part of this Julii Brainard has detected substantial errors within the woodland coverages of the ITE Land Cover Map, errors which have been acknowledged by the ITE. Similar concerns were raised with the author by Adrian Whiteman (Forestry Commission) in 1995.

[15] Note that a small farm level study of 10 farms has been conducted under the NELUP programme (Oglethorpe and O'Callaghan, 1995; Oglethorpe et al., 1995).

9.2.2.1: Modelling agricultural values: conclusions

Our review has highlighted a number of potential modelling approaches. Duality theory and the methodology of the NELUP model suggests that a profit function approach would be appropriate for the assembled dataset. Furthermore, the farm level resolution of our financial and environmental data means that we can avoid many of the aggregation problems facing the NELUP model.

9.2.3: DEVELOPING A MODELLING METHODOLOGY

Hill (1990) notes that income is the prime determinant of farm level decision making. Following this an initial methodology was tested by attempting to explain simple measures of farm gate income[16] and its social value equivalent in terms of which activities were undertaken, the level of inputs and the environmental characteristics of the farm. However, analysis quickly established that such a single equation approach was hampered by multicollinearity between input and environmental variables (Bateman and Lovett, 1992). Further analysis revealed a three step process (*ibid*) whereby: (i) output decisions were initially constrained by policy rules (most noticeably whether or not a particular farm held a milk quota); (ii) then the range and intensity of inputs which a farmer would devote to a particular farm where determined by its environmental characteristics and the extent to which they could be modified, and finally; (iii) income values would be determined by the array and intensity of inputs permitted by the previous step.

Given that the policy framework is exogenous to the farmer (e.g. the allocation of milk quota can be taken as given) then it is only the latter two steps which are under the control of the individual farmer. We can then categorise farms by output type into various sectors (see section 9.4) within which a two stage modelling methodology characterises the farmers decision making process (and obviates the problem of multicollinearity)[17]. Here in the first stage we can relate some measure of profits (π) to the array and intensity of farm level inputs ($I_1, I_2, ..., I_m$) as detailed in equation (1):

$$\pi = f(I_1, I_2, ..., I_m) \tag{1}$$

[16]Please note that in this section the terms farm income and farm gate income are used interchangeably and refer to net benefits measures rather than simple revenue streams. Precise definitions are developed subsequently.

[17]This two-stage approach to addressing multicollinearity owes much to Smith and Desvousges (1986).

In the second stage of the modelling process we have the various inputs $(I_1, I_2,..., I_m)$ employed by a farmer being individually explained by the environmental characteristics $(E_1, E_2,..., E_n)$ and environmental modifications $(M_1, M_2,..., M_p)$ of the particular farm. Equation (2) details the resulting equation set.

$$
\begin{aligned}
I_1 &= f(E_1, E_2,..., E_n, M_1, M_2,..., M_p) \\
I_2 &= f(E_1, E_2,..., E_n, M_1, M_2,..., M_p) \\
&\vdots \\
I_m &= f(E_1, E_2,..., E_n, M_1, M_2,..., M_p)
\end{aligned}
\tag{2}
$$

Such a modelling methodology fits in well with our overall research aim of assessing the spatial variation in the net benefits of transferring land from agriculture into woodland. The environmental variables $(E_1, E_2,..., E_n)$ are held as GIS images for the entire coverage of the study area. Therefore by holding the modification variables $(M_1, M_2,..., M_n)$ at appropriate levels for the sector under consideration we can produce maps of predicted levels for all inputs $(I_1, I_2,..., I_m)$. By estimating equation (1) for our sectoral farm sample we obtain profit function coefficients for these input variables and by applying these to our maps of predicted input levels we obtain estimates of farm income for the entire study area.

9.3: THE DATA

The models detailed above require farm-level data on both environmental characteristics and the variety of input, output and related variables which define a farm. Environmental data was taken from the LandIS database[18] while the Farm Business Survey of Wales (FBSW) provided the necessary farm data for this study[19], the details of which are

[18]We wish to repeat our thanks to the SSLRC for provision of this data. Section 9.6 discusses amongst other items the extraction, compilation and characteristics of a farm-level environmental dataset.

[19]We cannot overstate our thanks to FBSW who provided data for Wales which MAFF, even with guarantees of anonymity for individual farms, flatly refused to provide for England. In particular we are grateful to Tim Jenkins, Nigel Chapman and the surveyors at FBSW, Aberystwyth, without whom this work would have been infeasible.

briefly reviewed below.

9.3.1: THE FBSW DATASET

During the 1989/90 study period the FBSW interviewed and obtained full accounts data for a representative sample of 571 farms across Wales. Access to the full dataset was permitted, although interviews with surveyors showed that many of these farms were unsuitable for inclusion in the present study either because they were located on two or more sites or because the farm covered a diversity of environments. One particular problem was the number of farms which occupied both lowland and upland areas (affording winter shelter and summer grazing). Farms with large non-agricultural incomes were also excluded leaving a final sample of 240 farms.

The FBSW dataset is based upon full details of the annual accounts of the sample (which by law have to be surrendered, upon demand, to the FBSW). It is consequently a highly detailed and rich dataset. The depth of detail is illustrated in table 9.1 which presents the farm account framework in full as obtained (to ensure anonymity, typical rather than actual numbers for a farm of this type are used)[20]. Definition of the relevant measures of farm income and social value is considered in section 9.5 below.

9.4: CLUSTER ANALYSIS AND DESCRIPTION OF FARM SECTORS

Initial analysis showed that clear differences existed between different groups of farms, most noticeably in terms of principal activity and resultant income levels (Bateman and Lovett, 1992). Ignoring this issue is liable to lead to the under estimation of standard errors and exaggeration of the degree of explanation of any single model applied across all farms. Rather than adopt ad hoc rules for sectoral definition, a cluster analysis was undertaken analysing farm-level data concerning each of the activities engaged in by individual farms[21]. Full details of this analysis are provided in Appendix 7.1 with summary details as follows.

[20]FBSW survey number and OS grid reference were supplied but are made up in this example (with the location given being in the middle of Cardigan Bay).

[21]The FBSW data (table 9.1) identifies the following output groups: dairy; other cattle (beef); sheep; pigs; poultry; other livestock; crops; miscellaneous.

Table 9.1: FBSW annual farm account data: example of a typical farm record.

Farm type: Specialist Dairy Business size group: 24-39.9 BSU Farm number: 12345 Location (OS grid ref): Easting 2170; Northing 3010

Farm area (excluding common grazings)	- actual hectares	67.64	Size of business (BSU) : 37.35
	- effective hectares	64.80	Year ending : 31st March 1990

OUTPUTS BY VALUE[1]

Dairy	- milk	111526	
	- cattle	-160	
	- net milk quota[3]	2671	
	- valuation change	534	114621
Other cattle	- cattle	24935	
	- valuation change	-10048	14887
Sheep	- wool	119	
	- sheep	2517	
	- valuation change	439	3075
Pigs	- pigs	0	
	- valuation change	0	0
Poultry	- eggs	0	
	- poultry	0	
	- valuation change	0	0
Other livestock	livestock	0	
	- valuation change	0	0
Crops	- main crops	0	
	- by-products,forage & cults	-8540	-8540
Miscellaneous[8]		0	0
FARM OUTPUT			124043

INPUTS BY VALUE[2]

Feed	- purchased concentrates	31063	
	- home-grown concentrates	952	
	- purchase bulk feed	858	32873
Tack and stock keep			1929
Veterinary & medicines			3069
Other livestock costs[4]			10158
Seeds	- purchased	213	
	- home-grown	0	213
Fertilisers			9086
Other crop costs[5]			1340
Paid labour[6]	- regular	0	
	- casual	0	0
Machinery	- contract work	771	
	- repairs	2555	
	- fuels	1774	5100
General farm costs[7]			5165
Land expenses			5395
FARM INPUT			74328

FARM SURPLUS 49715

Subsidies & grants	- cattle	0	
	- sheep	269	
	- miscellaneous	0	269
FARM REVENUE			124312

Rent and rates	70
FARM EXPENSES	74398

EXCESS OF REVENUE OVER EXPENSES 49914

Notional outputs	- benefit value	
	- of farm houses	407
TOTAL OUTPUT		124719

Notional inputs	- rental value/imputed rent	5350	
	- unpaid labour	7415	12765
Machinery depreciation			8843
TOTAL INPUT			96006

NET FARM INCOME 28713 (of which BLSA[9] 1476)

Table 9.1 (cont.)

INCOME MEASURES	
Net Farm Income	28713
less, value of manual labour of farmer & spouse	7282
Investment Income	21431
plus, value of managerial input of paid managers	0
Management & Investment Income	21431

EFFICIENCY MEASURES	
Milk yield per cow (litres)	5745
Milk sales per cow (by value)	1097.40
Lambs reared per ewe (nos.)	1.17
Fat lamb sales per ewe[10] (nos.)	1.17
Return on tenant's capital (%)	14.04
Standard man-day availability[11]	650
Standard man-day requirement[11]	1118

TENANT'S CAPITAL	Opening value	Closing value	Average value per eff. ha.
Livestock	81175	72150	1183
Machinery	68549	67703	1051
Crops	10640	2100	98
Stores	1750	1200	22
Total tenant's capital	162114	143153	2355

LAND UTILISATION (Hectares)	Actual	Effective
Tillage - cereals	0.00	0.00
Tillage - roots & fodder	0.00	0.00
Grassland - hay	0.00	0.00
Grassland - silage	42.53	42.53
Grassland - pasture	22.27	22.27
Fallow & land let	0.00	0.00
Rough grazing - sole	0.00	0.00
Woods, roads & buildings	2.84	0.00
Total area	67.64	64.80
Rough grazing - common		0.00
Bare land and forage hired		4.05

LIVESTOCK	Opening Number	Opening Value	Closing Number	Closing Value	Average Number	Valuation Change	BLSA
Dairy cattle	111	45976	109	46560	101.5	584	1206
Other cattle	102	33658	93	23610	106.0	-10048	170
Sheep	46	1541	44	1980	65.7	439	100
Pigs	0	0	0	0	0.0	0	0
Poultry	0	0	0	0	0.0	0	
Other livestock	0	0	0	0	0.0	0	
Total livestock	259	81175	246	72150	273.2	-9025	1476

Notes.

1. Outputs include any produce given to workers and consumed or used on the farm. Outputs of livestock are given net of any purchases made. Output includes valuation changes which are detailed in the section headed 'Livestock'. Milk output includes quota transactions and any superlevies paid have been deducted.
2. Inputs include stock changes as well as purchases made during the year.
3. Net milk quota comprises quota compensation payments, payments for quota leased in and "leased out", and super levy payments where applicable.
4. Other livestock costs include purchased bedding materials, and other costs incurred specifically for livestock enterprises.
5. Other crop costs include crop protection chemicals and other costs incurred specifically for crop enterprises and forage.
6. Labour costs include cash wages and salaries, other employer's expenses, and the value of perquisites.
7. General farm costs include electricity, water and telephone charges, licences, insurances, subscriptions, etc.
8. Miscellaneous output includes contract work, farm cottage rents and profit on resale of purchased agricultural produce.
9. BLSA = breeding livestock stock appreciation - i.e. that part of livestock valuation changes relating to the breeding "stock on the farm". Details are given in the section headed 'Livestock'.
10. On some farms, fat lamb sales per ewe will include fat lambs from the previous year's lamb crop.
11. Standard man-day availability is the number of 8 hour "man-days used on the farm during the year. Standard man-day "requirement is the number of 8 hour man-days" conventionally regarded as necessary to maintain the farm's enterprises during the year.

Analysis showed that, using standard clustering diagnostics (Ward, 1963; Johnston, 1978; Norusis, 1985), farms could justifiably be grouped into six relatively homogeneous clusters. Table 9.2 details output type and income level characteristics for these clusters.

Table 9.2: Characteristics of six farm clusters

Cluster No.	Farms	Milk	Cattle	Sheep	OLivstock	Crops	Misc	Income (£/ha)
1	86	0.00365	0.29674	0.64410	0.00121	0.03414	0.00487	83.40
2	107	0.77759	0.11065	0.07050	0.00524	0.02447	0.00326	508.64
3	29	0.01793	0.63872	0.28345	0.00490	0.01900	-0.00614	47.09
4	10	0.17160	0.27690	0.39510	0.00360	0.00830	0.13490	222.84
5	2	0.00000	0.18150	0.07750	0.74600	-0.01100	0.00050	1145.43
6	6	0.05100	0.20083	0.14283	0.00883	0.56550	0.01200	57.50
All	240	0.35857	0.25092	0.31717	0.00995	0.04104	0.00854	282.61

It was decided that there was insufficient sample size to justify further analysis of clusters, 3 to 6. This left the two principal agricultural sectors of Wales; farms in cluster 1 specialising in sheep production with substantial production of beef cattle (hereafter referred to as 'sheep' farms) and; farms in cluster 2 specialising in dairying (hereafter referred to as 'milk' farms).

As a final test of sectoral homogeneity standard diagnostic tests for outliers were employed (Minitab, 1992). This identified one outlier amongst cluster 1 (sheep) and three amongst cluster 2 (milk). These farms were omitted to leave a final sample of 85 sheep farms and 104 milk farms.

The most striking difference between these two clusters was a wide disparity in income levels with mean net income per ha on milk farms being nearly six times that on sheep farms. Table 9.3 details descriptive statistics for this variable across these two clusters.

Table 9.3: Descriptive statistics of net income/ha (£) for cluster 1 (sheep) and 2 (milk)

Cluster No.	No. of farms	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX	Q1	Q3
1	85	81.8	77.0	84.8	123.8	13.5	-205.0	370.3	5.5	173.9
2	104	488.7	445.4	478.6	294.0	28.7	-100.4	1271.5	254.9	675.6

Descriptive statistics and correlation coefficients for all FBSW variables across both clusters are detailed in Appendix 7.1.

9.5: DEFINING FARM GATE INCOME AND THE SOCIAL VALUE OF AGRICULTURAL OUTPUT

An issue which proved more complex than expected was the definition of appropriate measures of what the farmer perceives as his/her annual net income (which we term farm gate income: FGI) and of the social value (SV) equivalent of this. This section details the definition of both variables. However, firstly all relevant variables were converted onto a common per hectare basis[22] with separate variables being added to the data set permit the analysis of any scale effects.

9.5.1: DEFINING FARM GATE INCOME

An immediately appealing measure in the FBSW dataset is the 'Net Farm Income' (NFI) variable (see table 9.1). However, following initial investigation (Bateman and Lovett, 1992) this variable was found to be unsuitable for our wider modelling requirements because, while its output minus input part ('Farm Surplus') is, as expected, negatively correlated with decreases in the quality of the physical farm environment (the variables E_1, E_2,.., E_n), the opposite relationship occurs with respect to the 'Subsidies and Grants' constituent of NFI[23]. This tends to remove the link between environmental adversity and income levels which is a prime focus of our study.

[22]This was achieved by dividing by the effective farm size (ha), a measure which ignores land classed by the FBSW as unusable (e.g. bare rock, roads, etc.).

[23]This is in itself interesting as it shows that, in general, subsidies and grants do compensate for environmental adversity. Further complexity arises because the unpaid labour element of NFI is positively correlated with such adversity; i.e. farmers attempt to combat poor physical environments by devoting relatively more labour to the farm.

The definition of the correct measure of farm income is inherently problematic and is itself the subject of research (Sturgess, 1996). Following conversations with Tim Jenkins (FBSW Director, Aberystwyth)[24] it was decided to base our statistical investigations of agricultural value upon the Farm Surplus variable with subsequent adjustments of predicted values to estimate FGI. An appropriate definition was agreed with Tim Jenkins as per equation (3):

$$\text{FGI} = \text{Farm Surplus} + \{\text{Subsidies and grants - Rent and rates - Depreciation} \qquad (3)$$

Using this we can use observations on {.} in (3) to define an adjustment variable ADJFGI which is the absolute difference (in £/ha) between Farm Surplus and FGI. This variable was defined for both the sheep and milk sectors (producing variables ADJFGIS and ADJFGIM respectively).

Given our observations at the start of this section we might expect there to be a relationship between these variables and farm-level environmental variables. Tests (detailed in Appendix 9.3) showed that this was indeed the case for the sheep sector although not for the milk farms. This is not surprising as milk farms receive relatively little in the way of direct subsidies and grants, most support being via prices (see following section), while sheep farms depend heavily upon area based direct payments. Consequently a single flat rate value of approximately minus £95 was found to be adequate for the milk farm sector variable ADJFGIM. By contrast the sheep farm sector variable ADJFGIS was generally positive and was found to be best predicted by equation (4):

$$\underset{}{\text{ADJFGIS}} = \underset{(-5.62)}{-720} + \underset{(5.61)}{0.0842}\ \text{Easting} + \underset{(4.02)}{95.7}\ \text{lnFCDays} \qquad (4)$$

$n = 84 \qquad R^2\,(\text{adj}) = 43.5\% \qquad R^2\,(\text{adj}) = 42.1\%$

Figures in brackets are t-statistics

where:

Easting	=	OS four figure Easting grid coordinate
lnFCDays	=	nature log of the number of field capacity days

[24]Talking in Summer 1995.

Equation (4) shows, as expected, that as the physical environment worsens so the difference between Farm Surplus and FGI rises. This is because of increases in the subsidies and grants element of FGI in more adverse environments. Both the explanatory variables are acting as indicators of such adversity, the lnFCDays variable being the most straightforward to interpret (see chapter 7) while the Easting variable acts as a proxy for the roughly linear mountain line which dominates the north-south axis of Wales. While this latter variable may result in some overstatement of ADJFGIS in the eastern extremes of Wales, inspection of predicted values indicated that this was a minor problem (see Appendix 7.2) and more than compensated for by the improvement over a constant value afforded by equation (4).

In summary, the values of Farm Surplus predicted by our estimated models of equations (1) and (2) can now be adjusted to produce estimates of FGI by, in the case of milk farms, the constant ADJFGIM and, for sheep farms, the variable ADJFGIS as predicted by equation (4).

9.5.2: DEFINING SOCIAL VALUES

The farm gate price received by farmers for their produce tells us the financial value (to farmers) of that output but it does not necessarily correspond to the value to society of that output. In order to estimate this shadow value we need to adjust for the following factors:

1. Market price support;
2. Direct subsidies and grants;
3. Input subsidies;
4. Levies;
5. Impacts of the above upon world price levels.

The methods by which each item is accounted for is briefly outlined below.

9.5.2.1: Market price support

The Organisation for Economic Cooperation and Development produce, for each of it's national members, annual estimates both of the value of output and the value of market price support disaggregated for all major farm products. (OECD, 1992). Using this information, a rate of market price support can be calculated and subtracted from the market price of the goods concerned.

9.5.2.2: Direct subsidies and grants

OECD (1992) also gives values for the amount of direct subsidies and grants paid to farmers. However, unlike our market price support calculation, such a rate of support cannot be said to be a reasonable approximation of the direct payments received by each farm. Fortunately the FBSW data supplied for this research details individual farm direct subsidies and grants disaggregated to three headings: cattle; sheep; and miscellaneous. Consequently individual payments can be directly subtracted from the total output value of each farm.

9.5.2.3: Input subsidies

Rates of input subsidy for each output heading were calculated from data given in OECD (1992). Ideally we would wish to allocate costs to individual outputs and remove input subsidies from these different cost portions. However, given that the same inputs are used on a variety of outputs, such an allocation of costs was not possible. An alternative approach is to calculate input subsidy values for each output by applying relevant input subsidy rates to the value of each output. These can then be added to total input costs.

9.5.2.4: Levies

These are in effect negative market price supports and can be treated in the same manner. Whereas adjusting for market price support will lower shadow value (with respect to market price), adjusting for levies (where applicable) will reverse the direction of movement (although the value of levies is invariably far below that of market price support).

9.5.2.5: Impacts upon world price levels

The policy instruments above have had a considerable and depressing impact upon World market prices for agricultural produce which needs to be considered in our shadow pricing exercise (Rosenblatt et al., 1988). Roningen and Dixit (1989) provide estimates of the rates of world price increase of various farm products resulting from a general liberalisation of agricultural policy as implied by adjusting for the above instruments[25]. This adjustment

[25]Figures taken from Roningen and Dixit (1989; p.16, table 5).

is performed by firstly adjusting for market price support and levies after which the world liberalisation price increase is allowed for. For ease of computation a combined conversion factor allowing for all three of these elements has been calculated, an example of which is given in the following section.

9.5.2.6: Example: calculating the social value of milk

Appendix 7.2 calculates, with examples, social value adjustment factors for all of the outputs produced by our sample farms. Here we illustrate this calculation with reference to the social value of milk production for our 1989/90 study year. Table 9.4 details the basic data for this calculation.

Table 9.4: EC Milk Production Values 1989/90 (ECUm)

Value of production	34177.6
Market price support	22318.4
Reduction of input costs	3250.8
Direct payments	562.1
Levies	-348.5

Source: OECD (1992) and EC (1992)

Using the data in table 9.4 we can calculate the following rates of support:

Price support rate = 0.6530123

Input cost reduction rate = 0.0951162

Direct payments rate = 0.0164464

Levies rate = 0.0101967

In addition to the above Roningen and Dixit (1989) estimate the world price uplift factor resulting from a multinational liberalisation of agricultural policy for dairy products (the 'liberalisation factor') as being 1.653.

As noted above we can adjust for direct payments from the grants and subsidies data given in the FBSW dataset by simply basing our social value adjustment upon the Farm

Surplus figure (which omits such transfers). The input cost reduction subsidy can then be accounted for by inflating the cost side by the appropriate rate and recalculating Farm Surplus. Finally the other effects can be subsumed within a single social value adjustment factor (SVadj) as specified in equation (5)[26]:

SVadj = [1-(Price support rate - Levies rate)] * Liberalisation factor (5)

So for our milk example SVadj = 0.59, i.e. the social value of milk is substantially lower than its market price[27].

In reality farms are multi-output enterprises and each output stream has its own social value adjustment factor. To allow for this diversity, SVadj was calculated for all outputs and its aggregate equivalent calculated for each of the two farm sectors under investigation by weighting by the mean proportion of each activity in each sector. Given that our cluster analysis has produced relatively homogeneous sectors this seems a defensible simplification. Interestingly, while the sheep sector proved to be highly dependent upon direct payments, price support was a significantly larger factor on milk farms which also exhibited a larger positive effect upon world prices arising from trade liberalisation. The net effect was that SVadj was reasonably similar between the two sectors being about 0.55 for our 'milk' farms (SVadjm) and 0.60 for the mainly 'sheep' farms (SVadjs).

Finally SV can be calculated by multiplying Farm Surplus by the relevant sectoral value of SVadj.

9.5.3: SUMMARY

We have now established definitions whereby we can identify both FGI and SV. Both of these are derived from Farm Surplus. This in turn simplifies our modelling exercise meaning that we only have to estimate one set of equations (1) and (2) for each sector with π defined as Farm Surplus in equation (2). We now turn to consider the definition of the environmental explanatory variables in those equations.

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[26]Many thanks to Professor A.J. Rayner for clarification here.

[27]A difference which becomes slightly larger when we consider the impact of removing input cost subsidies.

9.6: PRINCIPAL COMPONENTS ANALYSIS OF FARM LEVEL ENVIRONMENTAL VARIABLES

The environmental variable dataset is that previously described in our analysis of timber yield (Chapter 7), i.e. that obtained from the SSLRC LandIS database. As per that analysis records for all environmental variables were, where necessary, converted from a 5km to 1km resolution through GIS image expansion and interpolation routines. Data was then extracted for each farm location. Transformations to permit analysis of natural logarithms, squares, etc. of these variables were undertaken using the appropriate GIS commands[28].

As per our methodology for investigating timber yields, it was decided to base our models of agricultural values on both the raw and transformed environmental data and on factors obtained from a principal components analysis (PCA) of that data.

Two PCA's were undertaken, one for each of our farm sectors. Both are described in detail in Appendix 7.3 and briefly summarised here. The PCA of sheep farms extracted four factors (eigenvalues >1) which together accounted for over 75% of the variation in the environmental variables. These were rotated using the varimax technique and factor score coefficients calculated as detailed in table 9.5 (variable labels and definitions can be found in Chapter 7).

Table 9.5: Factor score coefficient matrix: sheep farms

Variable	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
ACCTEMP	-.07451	-.15038	-.00965	.16801
RAINFALL	.30941	-.12910	-.07898	.15521
ENDMED	.29222	-.11039	-.03554	.10823
FCAPDAYS	.26242	-.06571	-.00271	.05730
MDEFGRA	-.21299	-.05362	.04012	-.01269
AVWATGRA	-.10131	.13490	.54490	-.05360
WORKABIL	-.00837	-.08761	.48830	-.00341
SPRMWD	.09565	-.05040	-.13722	.59982
WSELVGR2	-.05378	.45737	.02782	-.07937
DSL2	-.06190	.49060	.05975	.07004
COSASP	-.03171	.25757	-.19306	.04307
SINASP	-.09536	-.05436	-.07343	-.62396

Inspection of the factor score coefficient matrix allows us to interpret the factors for sheep farms as detailed in table 9.6.

[28]Namely the TRANSFOR command. Note that when log transformations were calculated, 0.01 was added to any land cell containing a zero valuation.

Table 9.6: Interpretation of environmental PCA factors for sheep farms

Factor label	Interpretation[1]
envPC1sh	High rainfall/low temperature
envPC2sh	High elevation/high slope
envPC3sh	High water availability/high workability score
envPC4sh	High machinery working days/Westerly aspect

Note: 1. See Chapter 7 and Appendix 5 for further definition of these terms.

The PCA of milk farms also extracted four factors which accounted for roughly 73% of variation in the environmental variables. These were again rotated and resultant factor score coefficients are detailed in table 9.7.

Table 9.7: Factor score coefficient matrix: milk farms

Variable	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
ACCTEMP	-.01586	-.00345	.12026	.71393
RAINFALL	.23903	-.02949	-.03907	.05902
ENDMED	.22911	.00882	-.03050	.00093
FCAPDAYS	.23606	-.01977	-.03776	.02087
MDEFGRA	-.20173	.07708	.04391	.14387
AVWATGRA	.04374	.46815	-.00902	-.02267
WORKABIL	-.04409	.53688	.05882	-.07404
SPRMWD	-.12631	-.13281	-.13035	-.12941
WSELVGR2	-.01280	.08309	.50946	-.03755
DSL2	-.02364	-.00867	.54109	.18269
COSASP	-.15431	.05427	.25268	-.46031
SINASP	-.00480	.28540	.11003	.33356

Interpretation of the PCA factors for milk farms is given in table 9.8.

Table 9.8: Interpretation of environmental PCA factors for milk farms

Factor label	Interpretation[1]
envPC1mk	High rainfall
envPC2mk	High workability score/high water availability
envPC3mk	High elevation/high slope
envPC4mk	High temperature/Southerly aspects

Note: 1. See Chapter 7 and Appendix 5 for further definition of these terms.

This analysis allowed the use of both raw variables and PCA factors to describe farm-level environmental characteristics in our sectoral models of agricultural value, to which we now turn.

9.7: MODELLING AGRICULTURAL VALUES: SHEEP FARMS

Regression analysis proceeded in line with the principles laid down by Lewis-Beck (1980), particular attention being paid to problems of multicollinearity. The 'stage 1' value function (equation (1)), was estimated initially. This identified the relevant explanatory input variables which formed the dependent variables in the 'stage 2' equation set (equation (2)).

9.7.1: STAGE 1 MODEL

The dataset was extensively investigated with a variety of specifications and functional forms being tested[29]. Model 9.1 reports the best fitting stage 1 model of Farm Surplus per effective hectare for our sample of sheep farms.

Model 9.1: Best fitting stage 1 model predicting Farm Surplus/ha[30] for sheep farms

Predictor	*Coef*	*Stdev*	*t-ratio*	*p*
Constant	-207.77	62.11	-3.35	0.001
lamb/ewe	180.87	36.38	4.97	0.000
$live/eh	0.15095	0.03823	3.95	0.000
$f&sLab	0.009840	0.003381	2.91	0.005
grants%	-210.43	97.82	-2.15	0.035

s = 73.44 R-sq = 62.1% R-sq(adj) = 60.2% n = 85[31]

where:

lamb/ewe = No. of lambs reared per ewe per annum (efficiency measure)
$live/eh = Value of livestock per effective hectare (input intensity)
$f&sLab/h = Notional value of farmer and spouse labour input per hectare
grants% = Total subsidies and grants (direct payments) expressed as a percentage of total farm revenue.

[29]All feasible variables in the dataset were investigated.
[30]All area measures (whether explicitly specified or not) are per effective hectare. This applies to all models and to both samples.
[31]One incomplete farm record.

Given its cross-sectional nature, model 9.1 achieves a high degree of explanation, exceeding that of many of the studies reviewed in section 9.2. The model also reveals some interesting detail regarding the optimisation of farm surplus on sheep farms. Surplus increases with livestock intensity ($live/eh), with the efficiency of that livestock (lamb/ewe) and with the labour a farmer and/or spouse devotes to the farm ($f&sLab/h). However, increased revenue dependency upon direct payments (grants %) is synonymous with relatively lower levels of Farm Surplus.

All these relationships conform to prior expectations and so we felt justified in entering the stage 1 explanatory variables as the dependent variables in the stage 2 equations to which we now turn.

9.7.2: STAGE 2 MODELS

Here we present predictive models for each of the four stage 1 explanatory variables. As discussed in section 9.2.3 we relate these to variables detailing the environmental characteristics of the farm and modifications to those characteristics. These environmental characteristics can either be assessed using raw data or by reference to the PCA factors calculated previously. The following sections examine each of these options in turn.

9.7.2.1: Stage 2 model using raw environmental variables

All the models in this section use raw environmental variables rather than PCA factors as predictors of the stage 1 input variables. Model 9.2 presents our best fitting model for predicting the number of lambs produced per ewe (lamb/ewe).

Model 9.2: Best fitting stage 2 model predicting lamb/ewe for sheep farms (not using PCA factors)

Predictor	*Coef*	*Stdev*	*t-ratio*	*p*
Constant	3.5101	0.5861	5.99	0.000
lnFCdays	-0.4521	0.1052	-4.30	0.000
Silag%	0.5918	0.1872	3.16	0.002
$crop/h	0.0010796	0.0004207	2.57	0.012

s = 0.1868 R-sq = 39.8% R-sq(adj) = 37.6% n = 85

where:

lnFCdays = Natural log of the number of days pa. for which soil is at field capacity.
Silag% = Proportion of farm area put to silage.
$crop/h = Value of crops per hectare.

Given its cross-sectional nature, model 9.2 achieves a reasonably good degree of explanation. Inspection of the model shows that the input efficiency measure lamb/ewe is lower for soils prone to waterlogging (lnFCdays) but improves where modification leads to better forage availability (Silag%, $crop/h). Consideration of these variables leads to a problem regarding how they should be treated when using the model to predict lamb/ewe for the study area. We have full coverage GIS images of all the environmental variables (i.e. an image for lnFCdays can readily be created) but not of the modification variables. A typical approach to such problems is to hold such variables at defensible constant values[32]. An analysis of the distribution of both modification variables showed them to be somewhat skewed and so, for the purposes of prediction, both were held at their median values ($crop/h = 19.50; Silag% = 0.145). Details of the distributions of these modification variables for our sheep and milk models are presented in Appendix 7.4.

Model 9.3 details the best fitting model for $live/eh.

Model 9.3: Best fitting stage 2 model predicting $live/eh for sheep farms (not using PCA factors).

Predictor	*Coef*	*Stdev*	*t-ratio*	*p*
Constant	2711.9	619.0	4.38	0.000
lnFCdays	-410.0	110.8	-3.70	0.000
SprMWD^2	1.4209	0.5831	2.44	0.017
Silag%	1035.8	168.8	6.14	0.000

s = 185.1   R-sq = 47.0%   R-sq(adj) = 45.0%   n = 85

where:

SprMWD^2 = Square of number of spring machinery working days
Other variables as previously defined.

Livestock intensity ($live/eh) is well predicted by model 9.3 being negatively related to increased susceptibility to waterlogging (lnFCdays) and positively related to improved accessibility (SprMWD^2) and forage availability (Silag%), the latter being treated as before in generating predictions of $live/eh. Model 9.4 predicts the notional value of farmer and spouse labour input ($f&sLab).

[32]See, for example, Garrod and Willis (1992 a,b,c).

Model 9.4: Best fitting stage 2 model predicting $f&sLab for sheep farms (not using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	-791	2688	-0.29	0.769
Endwet	37.86	14.59	2.60	0.011
SprMWD	-710.0	294.0	-2.41	0.018
SprMWD^2	78.59	24.05	3.27	0.002
<140eh	2191.4	616.4	3.56	0.001

s = 2114 R-sq = 28.8% R-sq(adj) = 25.2% n = 85

where:

Endwet = The end of field capacity period as measured in 'wet' years
<140eh = dummy for smaller farms, hold at median value = 1
Other variables as previously defined.

Model 9.4 is the weakest of the stage 2 equations for sheep farms and brings us to consider what degree of explanation is acceptable in these models. Conversation with experts in the field[33] highlighted the fact that we are dealing with cross-sectional data and so should not expect the somewhat inflated degrees of explanation typical of time-series analyses. Some guidance was provided by the contingent valuation literature, particularly that concerned with theoretical validation. Here Mitchell and Carson (1989) recommend that a minimum R^2 value of 15% should be used while Hanley (1990) recommends a 20% threshold. Erring on the side of safety we adopt a minimum value requirement for adjusted R^2 of 20%. Given this it was felt that model 9.4 was adequate for predictive purposes.

The model shows farmer and spouse labour input rising in more waterlogged areas (Endwet) and following a negative quadratic with respect to accessibility (SprMWD, SprMWD^2) suggesting that as accessibility declines so does labour input but at a declining rate indicative of some minimum level below which input will not fall. However, the strongest relationship is with farm size with small farms exhibiting significantly higher levels of farmer and spouse labour input[34].

[33] I am particularly grateful to Professor Chris Ennew (University of Nottingham) and Dr Ian Langford (UEA).

[34] Preliminary investigation was also made into a possible link with population density, the latter being used as an indicator of the availability of alternative employment opportunities. No clearly significant link was established although we have some reservations regarding the adequacy of available data for this analysis.

The final stage 2 equation for sheep farms, predicting the proportion of total farm revenue derived from subsidies and grants (grants%), is detailed in model 9.5.

Model 9.5: Best fitting stage 2 model predicting grants% for sheep farms (not using PCA factors).

Predictor	*Coef*	*Stdev*	*t-ratio*	*p*
Constant	-1.2915	0.2617	-4.94	0.000
lnFCdays	0.27151	0.04763	5.70	0.000
lnSlope	0.03207	0.01095	2.93	0.004

s = 0.08169 R-sq = 40.3% R-sq(adj) = 38.8% n = 85

where:

lnSlope = Natural log of mean farm slope angle
Other variables as previously defined.

The dependent grants% is purely predicted by environmental variables which provide a good degree of explanation. As discussed previously sheep farm grants are a function of environmental adversity, in this case increased waterlogging and slope.

We now re-estimate the models detailed in this section using the previously calculated PCA factors in place of the environmental variables used here.

9.7.2.2: Stage 2 models using PCA environmental factors

Models 9.6 to 9.9 detail the four stage 2 models for sheep farms estimated using PCA factors as environmental explanatory variables. Table 9.6 provides interpretation of these factors.

Model 9.6: Best fitting stage 2 model predicting lamb/ewe for sheep farms (using PCA factors).

Predictor	*Coef*	*Stdev*	*t-ratio*	*p*
Constant	0.98250	0.03991	24.62	0.000
Silag%	0.6490	0.2298	2.82	0.006
$crop/h	0.0012216	0.0005143	2.38	0.020
envPC1sh	-0.06454	0.02510	-2.57	0.012

s = 0.2283 R-sq = 29.6% R-sq(adj) = 27.0% n = 85

Variables as previously defined.

Model 9.7: Best fitting stage 2 model predicting $live/eh for sheep farms (using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	462.82	34.01	13.61	0.000
Silag%	998.1	180.2	5.54	0.000
envPC1sh	-82.68	21.76	-3.80	0.000

s = 198.0 R-sq = 38.6% R-sq(adj) = 37.1% n = 85

Variables as previously defined

Model 9.8: Best fitting stage 2 model predicting $f&sLab for sheep farms (using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	5544.5	608.4	9.11	0.000
envPC1sh	521.6	258.5	2.02	0.047
<140ha	2214.4	674.2	3.28	0.002

s = 2294 R-sq = 13.1% R-sq(adj) = 10.9% n = 85

Variables as previously defined

Model 9.9: Best fitting stage 2 model predicting grants% for sheep farms (using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	0.235903	0.009929	23.76	0.000
envPC1sh	0.054512	0.009931	5.49	0.000
envPC2sh	0.020790	0.009931	2.09	0.039

s = 0.09100 R-sq = 29.9% R-sq(adj) = 28.2% n = 85

Variables as previously defined

Analysis of models 9.6 to 9.9 shows many similarities with those estimated without PCA factors. However, in every case the latter provide a higher degree of explanation and, given the perennial problems associated with fully interpreting PCA factors we have clear reasons to adjudge models 9.2 to 9.5 as our preferred description of the stage 2 equation set for sheep farms. Consequently we do not take our analysis of PCA factor-based models further.

9.7.3: PREDICTED FGI AND SV FOR SHEEP FARMS: WITHIN SAMPLE ANALYSIS

Prior to extrapolation across the entire study area we can demonstrate our methodology by using the estimated models to predict values for FGI and SV for our sample of sheep farms (FGIs and SVs respectively). Both of these variables are calculated from Farm Surplus as estimated using model 9.1. The adjustment factor ADJFGIS, linking Farm Surplus to FGIs is estimated using equation (4). The adjustment factors SVadjs linking Farm Surplus to SVs is calculated as detailed previously. Table 9.9 details descriptive statistics for all of these variables.

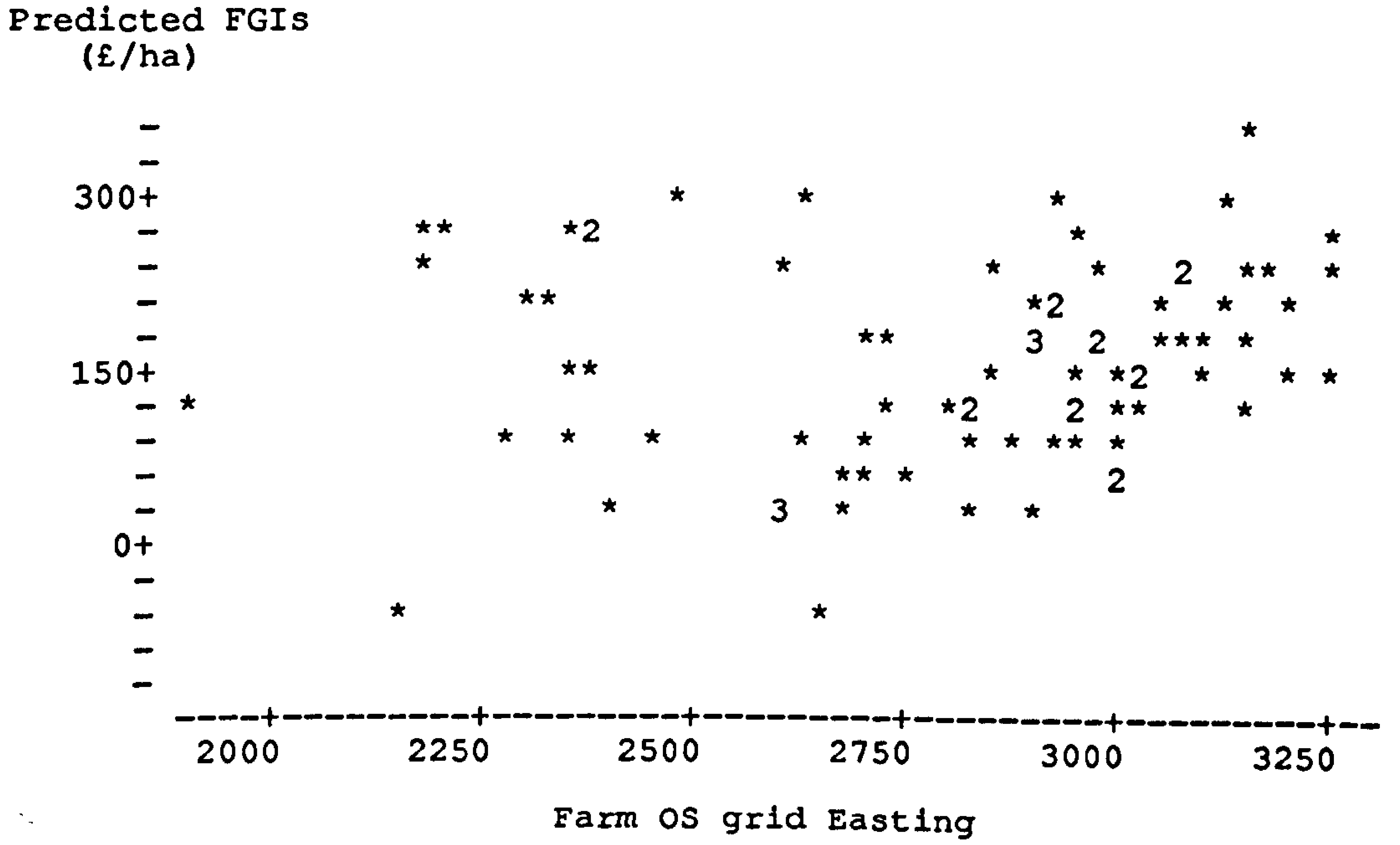
Table 9.9: Farm Surplus and predicted FGIs, SVs and associated adjustment factors (£/ha) for the sample of sheep farms.

Variable (£/ha)	*mean*	*median*	*st dev*	*semean*	*min*	*max*	*Q1*	*Q3*
Farm Surplus	110.90	101.50	91.80	10.00	-99.30	310.60	44.30	165.50
ADJFGIS	45.97	60.33	35.40	3.84	-37.68	100.52	24.24	71.80
FGIs	156.86	158.90	84.12	9.18	-71.78	348.20	97.05	225.16
SVs	86.30	87.42	46.28	5.05	-39.49	191.56	53.39	123.87

Table 9.9 shows that per hectare FGIs is relatively low when assessed against the roughly comparable net farm income measure for milk farms detailed in table 9.3. Furthermore, SVs is even lower than this indicating that sheep farming in the mainly upland study area is, economically speaking, a highly marginal enterprise.

One concern was that the Easting variable in equation (4) might exert an undue influence upon predictions of FGIs and SVs for farms at the far Western and Eastern extremes of the sample. However, figure 9.2, which plots the relationship between OS Easting and predicted FGIs indicates that this is not a serious problem.

Figure 9.2: Graph of predicted FGIs against farm OS Easting.



Key: * = one farm; 2 = two farms; etc.

We now extend our regression analysis to our sample of milk farms.

9.8: MODELLING AGRICULTURAL VALUES: MILK FARMS

This section is organised as per our analysis of sheep farms. We first present our stage 1 model, followed by stage 2 models estimated initially without and then with PCA factors. Finally we summarise the resultant predicted values.

9.8.1 STAGE 1 MODEL

Model 9.10 reports the best fitting stage 1 model of Farm Surplus per effective hectare on our sample of milk farms.

Model 9.10: Best fitting stage 1 model predicting Farm Surplus/ha for milk farms.

Predictor	Coef	Stdev	t-ratio	p
Constant	4.8	101.3	0.05	0.962
$live/eh	0.46656	0.06321	7.38	0.000
gShep%TO	-3543.2	690.9	-5.13	0.000
genC/h	1.6977	0.6164	2.75	0.007
$mlk/cow	0.24095	0.09029	2.67	0.009
pLab/h	-0.5101	0.1940	-2.63	0.010
catt%FR	-460.6	189.7	-2.43	0.017

s = 179.6 R-sq = 67.4% R-sq(adj) = 65.4% n = 104

where:

$live/eh	=	Value of livestock per effective hectare (input intensity)
gShep%TO	=	Sheep grants expressed as a percentage of farm total output value
genC/h	=	General farm costs (electricity, water and telephone charges, licences, insurances, subscriptions, etc.) per hectare (input intensity)
$mlk/cow	=	The value of milk produced per cow (efficiency measure)
pLab/h	=	Value of paid labour per hectare (efficiency measure)
catt%FR	=	Value of cattle output expressed as % of total farm revenue

Our stage 1 model for milk farms performs even better than that for sheep farms achieving a very satisfactory degree of explanation given that this is a cross-sectional analysis. As before we find positive relationships between Farm Surplus and input intensity ($live/eh, genC/h). Similarly farm efficiency is a clear determinant of Farm Surplus which increases with the value of milk produced per cow ($mlk/cow)[35] and falls as more paid labour is required per hectare (pLab/h). Finally, we have two variables showing that where farms have to increasingly rely upon lower margin, non-core activities such as sheep and cattle (gShep%TO, catt%FR) so Farm Surplus values tend to decline.

All these relationships conform to prior expectations and justify the entry of stage 1 explanatory variables as dependent variables in the stage 2 equation set.

9.8.2: STAGE 2 MODELS

This section is arranged as before. First we present those stage 2 models estimated using raw data environmental variables as predictors of the input variables specified above. These models are then re-estimated using the environmental PCA factors estimated previously.

[35] This is analogous to the lamb/ewe variable in the stage 1 model for sheep farms.

9.8.2.1: Stage 2 models using raw environmental variables

Model 9.11 presents our best fitting model predicting livestock intensity ($live/eh) on milk farms.

Model 9.11: Best fitting stage 2 model predicting $live/eh for milk farms (not using PCA factors)

Predictor	*Coef*	*Stdev*	*t-ratio*	*p*
Constant	468	1659	0.28	0.778
lnEwet	-736.8	270.9	-2.72	0.008
lnAWpot	804.6	279.0	2.88	0.005
Reg456	140.24	68.55	2.05	0.043
pConc/h	0.7432	0.1551	4.79	0.000
Fert/h	2.2962	0.6231	3.69	0.000

s = 263.4 R-sq = 46.7% R-sq(adj) = 44.0% n = 104

where:

lnEwet = Natural log of the end of field capacity period as measured in 'wet' years
lnAWpot = Natural log of available water; measured for potato crop
Reg456 = Farm in SSLRC relief regions 4, 5 or 6 (lowland)[36]
pConc/h = Value of purchased concentrates per hectare.
Fert/h = Value of fertiliser per hectare.

Model 9.11 fits the cross-sectional data well. Livestock intensity declines in areas of higher waterlogging risk (lnEwet) and rises in areas considered suitable for delicate crops (lnAWpot). There is also a positive general association with lowland areas (Reg456). Farmers can also improve the ability of the farm environment to support livestock both directly through the use of fertilisers (Fert/h) and indirectly through inputs of concentrates (pConc/h). As with our sheep models, for predictive purposes data on the environmental variables (here lnEwet, lnAWpot and Reg456) is available for the entire study area as GIS generated images. However, as before we hold the modification variables (here Fert/h and pConc/h) at representative constant values. In model 9.11 both modification variables exhibit a slightly skewed distribution and so are held at their median values (pConc/h = 241.2; Fert/h = 88.36).

[36]Variable taken from Rudeforth et al., (1984), p.19, as digitised by Gila Sunenberg.

Model 9.12 presents our best fitting model predicting the percentage of farm total output value derived from direct payments for sheep (gShep%TO) on our mainly milk farms.

Model 9.12: Best fitting stage 2 model predicting gShep%TO for milk farms (not using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	0.12787	0.06629	1.93	0.057
Enddry	-0.002559	0.001094	-2.34	0.021
EnddrySq	0.00001365	0.00000446	3.06	0.003

s = 0.02256 R-sq = 25.4% R-sq(adj) = 23.9% n = 104

where:

Enddry = End of field capacity period as measured in 'dry' years.
EnddrySq = Enddry * Enddry

The variable gShep%TO exhibits a quadratic relationship with the waterlogging measure Enddry, falling at a declining rate as the end of field capacity period increases. Model 9.12 is relatively weak compared to previous stage 2 models. Nevertheless it does satisfy our theoretical validity criteria. However, this is not true of model 9.13 which predicts the general farm costs per hectare input intensity measure (genC/h).

Model 9.13: Best fitting stage 2 model predicting genC/h for milk (not using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	44.19	12.75	3.47	0.001
AWgrSq	0.0016590	0.0007713	2.15	0.034
f&sLab/h	0.08119	0.01848	4.39	0.000

s = 31.95 R-sq = 21.2% R-sq(adj) = 19.6% n = 104

where:

AWgrSq = Square of water availability for grass crop
f&sLab/h = Notional value of farmer and spouse labour input per hectare

Model 9.13 just fails our minimum fit criteria (R^2adj = 20%) and accordingly we have grounds for doubting the validity of using such a model to predict the input genC/h in the stage 1 model for milk farms. However, inspection of genC/h showed it to be reasonably normally distributed across farms and so it was decided to hold it at its mean value (85.23) in the stage 1 equation[37]. This is clearly not ideal but it is a recognised and unbiased way of addressing such a problem.

Model 9.14 presents our best fitting model predicting the input efficiency measure $mlk/cow (the value of milk produced per cow) for our milk farm sample.

Model 9.14: Best fitting stage 2 model predicting $mlk/cow for milk farms (not using PCA factors).

Predictor	*Coef*	*Stdev*	*t-ratio*	*p*
Constant	481.0	107.1	4.49	0.000
soil2&3	152.25	39.44	3.86	0.000
AWcer^2	0.015997	0.004899	3.27	0.002
SprMWD	-11.141	4.219	-2.64	0.010
Reg456	84.10	36.70	2.29	0.024
f&sLab/h	-0.37559	0.08469	-4.43	0.000
pConc/h	0.33631	0.08351	4.03	0.000

s = 152.2 R-sq = 33.2% R-sq(adj) = 29.0% n = 104

where:

soil2&3 = Farm located on soil types 2 and/or 3
Awcer^2 = Water availability for cereals
SprMWD = Spring machinery working days
Other variables as previously defined.

Model 9.14 provides a reasonable degree of explanation of $mlk/cow however a collinearity problem between the two variables Awcer^2 and SprMWD (both of which are related to soil moisture) makes their interpretation problematic. Nevertheless, these variables were retained on the grounds that they substantially improved prediction of the dependent, which is the prime purpose of the stage 2 models. Other variables are more straightforward to interpret. Soil classes 2 and 3 refer to some of the best soils found in the study area[38] while the variable Reg456 indicates lowland areas. As expected both are positively related to milk yields as is higher levels of concentrate usage (pConc/h)[39]. Interestingly, and converse

[37]So in the stage 1 model we multiply the coefficient on genC/h by the mean value of the variable, i.e. 1.6977 * 85.23 = 144.7.

[38]See chapter 7 for further details.

[39]Tests revealed no significant multicollinearity problem.

to sheep farms, on milk farms higher levels of labour input seem to be an indicator of inefficiency and consequent lower yields. This seems reasonable and is backed up by the negative sign on paid labour input in the stage 1 milk farm model. It seems that whereas low income levels mean that sheep farmers have no option but to devote additional unpaid labour to their farms, milk farms are generally operating at a much higher level of efficiency where profit maximisation can often be enhanced through cost reductions.

As before the modification variables are held as constants where the stage 2 models as used for predictive purposes. Here both f&sLab/h and pConc/h were found to have somewhat skewed distributions and so were held at median values of 135.6 and 241.2 respectively.

Model 9.15 presents our best fitting model predicting another input efficiency measure, pLab/h, the value of paid labour per hectare on milk farms.

Analysis of model 9.15 shows that the level of paid labour employed on farms is lower in areas of relative environmental adversity (Rain^2, MdefCerl, Elev^2) and higher in areas were the environment is more benign (Grazseas, Enddry^2). It is perhaps not surprising to find that the amount of paid labour on farms is inversely related to the farmer and spouse labour input, suggesting that as a farmers income increases so he/she substitutes paid labour for personal effort. For predictive purposes f&sLab/h is held at its median of 135.6.

Model 9.15: Best fitting stage 2 model predicting pLab/h for milk farms (not using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	227.30	85.74	2.65	0.009
Rain^2	-0.00032227	0.00007866	-4.10	0.000
MdefCerl	-4.802	1.049	-4.58	0.000
Grazseas	1.0426	0.3293	3.17	0.002
Enddry^2	0.03204	0.01058	3.03	0.003
Elev^2	-0.0006020	0.0002370	-2.54	0.013
f&sLab/h	-0.14678	0.04957	-2.96	0.004

s = 90.10 R-sq = 30.9% R-sq(adj) = 26.7% n = 104

where:

Rain^2 = Square of the average rainfall (mm pa.) on farm.
MdefCerl = Soil moisture deficit for cereals.
Grazseas = Length of grazing season (days pa.).
Elev^2 = Square of farm elevation (m) above sea level.
Other variables as previously defined.

Model 9.16 presents our last stage 2 model, predicting catt%FR, an indicator of a particular, lower margin, non-core activity on our milk farms.

Model 9.16: Best fitting stage 2 model predicting catt%FR for milk farms (not using PCA factors).

Predictor	*Coef*	*Stdev*	*t-ratio*	*p*
Constant	0.09269	0.01267	7.31	0.000
lnSlope	-0.022331	0.008983	-2.49	0.015
sinAsp	-0.02623	0.01217	-2.16	0.033
ehaHay	0.008152	0.002415	3.38	0.001

s = 0.09027 R-sq = 18.6% R-sq(adj) = 16.1% n = 104

where:

lnSlope = Natural logarithm of average slope on farm
sinAsp = Sine of aspect
ehaHay = Absolute area (ha.) of farm put to hay

Model 9.16 fails our criterion of theoretical validity. However, catt%FR was reasonably normally distributed and was consequently set to its mean value (0.1107) for predictive purposes within the stage 1 equation for milk farms[40].

We now re-estimate the stage 2 models for milk farms using the previously calculated PCA factors in place of the environmental variables used above.

9.8.2.2: Stage 2 models using PCA environmental factors

Models 9.17 to 9.22 detail the six stage 2 models for milk farms estimated using PCA factors as environmental explanatory variables. Table 9.8 provides interpretation of these factors.

[40] So in the stage 1 model we multiply the coefficient on catt%FR by the mean value of the variable, i.e. -460.6 * 0.1107 = -50.9884.

Model 9.17: Best fitting stage 2 model predicting $live/eh for milk farms (using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	579.20	65.71	8.81	0.000
envPC1mk	-58.55	27.58	-2.12	0.036
pConc/h	0.7687	0.1624	4.73	0.000
Fert/h	2.4680	0.6290	3.92	0.000

s = 277.5 R-sq = 39.6% R-sq(adj) = 37.8% n = 104

Variables as previously defined

Model 9.18: Best fitting stage 2 model predicting gShep%TO for milk farms (using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	0.015232	0.002525	6.03	0.000
envPC1mk	0.008260	0.002525	3.27	0.001
envPC2mk	0.005087	0.002554	1.99	0.049
envPC4mk	-0.005239	0.002527	-2.07	0.041

s = 0.02563 R-sq = 16.0% R-sq(adj) = 13.5% n = 104

Variables as previously defined

Model 9.19: Best fitting stage 2 model predicting genC/h for milk (using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	71.774	4.675	15.35	0.000
envPC2mk	4.622	3.267	1.41	0.160
f&sLab/h	0.07154	0.01787	4.00	0.000

s = 33.14 R-sq = 14.9% R-sq(adj) = 13.3% n = 104

Variables as previously defined

Model 9.20: Best fitting stage 2 model predicting $mlk/cow for milk farms (using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	869.59	35.02	24.83	0.000
envPC1mk	19.71	16.84	1.17	0.245
f&sLab/h	-0.30806	0.09130	-3.37	0.001
pConc/h	0.31358	0.08960	3.50	0.001

s = 165.3 R-sq = 18.7% R-sq(adj) = 16.2% n = 104

Variables as previously defined

Model 9.21: Best fitting stage 2 model predicting pLab/h for milk farms (using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	88.66	11.71	7.57	0.000
envPC1mk	-19.491	8.231	-2.37	0.020
f&sLab/h	-0.11369	0.04504	-2.52	0.013

s = 81.61 R-sq = 13.2% R-sq(adj) = 11.4% n = 104

Variables as previously defined

Model 9.22: Best fitting stage 2 model predicting catt%FR for milk farms (using PCA factors).

Predictor	Coef	Stdev	t-ratio	p
Constant	0.08002	0.01227	6.52	0.000
envPC1mk	-0.010278	0.009320	-1.10	0.273
ehaHay	0.008665	0.002516	3.44	0.001

s = 0.09387 R-sq = 11.1% R-sq(adj) = 9.3% n = 104

Variables as previously defined

As was observed in our study of sheep farms, analysis of models 9.17 to 9.22 shows many similarities with those estimated without PCA factors. However, in every case the latter provide a higher degree of explanation and, given the perennial problems associated with fully interpreting PCA factors we have clear reasons to adjudge models 9.11 to 9.16 as our preferred description of the stage 2 equation set for milk farms. Consequently we again do not take our analysis of PCA factor-based models further.

9.8.3: PREDICTED FGI AND SV FOR MILK FARMS

As before, we demonstrate our methodology by using our estimated models to predict values of FGI and SV for our sample of milk farms (producing variables FGIm and SVm respectively). The relevant adjustment factors ADJFGIM and SVadjm are both constants defined as detailed previously. Table 9.10 details descriptive statistics for Farm Surplus and predicted FGIm and SVm.

Table 9.10: Farm Surplus and predicted FGIm and SVm for the sample of milk farms.

Variable (£/ha)	MEAN	MEDIAN	STDEV	SEMEAN	MIN	MAX	Q1	Q3
Farm Surplus	703.8	655.6	306.0	30.0	215.2	1442.4	440.4	905.2
FGIm	608.4	560.3	306.0	30.0	119.9	1347.1	345.0	809.9
SVm	422.6	393.6	183.7	18.0	129.2	866.1	264.4	543.5

Comparison of table 9.10 with table 9.9 illustrates the very wide divergence in FGI between the two farm sectors with milk farms earning almost four times the per hectare income of sheep farms. However, this has to be tempered by the knowledge that, on average, sheep farms are substantially larger than milk farms (see table 9.11). Taking account of this size difference implies a mean farm income of about £16,000 on sheep farms and £43,000 on milk farms, i.e. the latter earn over 2.5 times what the former receive.

Table 9.11: Farm size by sector (effective hectares)

Sector	mean	median	trmean	st dev	semean	min	max	Q1	Q3
sheep	102.38	92.34	98.31	54.70	5.93	25.92	358.87	60.99	130.60
milk	70.86	58.16	64.41	55.46	5.44	8.89	396.90	37.82	80.90

Comparison of social values is also interesting. In both cases SV is substantially below FGI. However, while SVm is nearly 70% of FGIm, SVs is only 55% of FGIs. Therefore in both market and social terms, sheep farming is the poor relation of the dairying sector[41].

We now apply out various stage 1 and 2 models to the prediction of FGI and SV for both sectors across the entirety of the study area.

9.9: MAPPING MARKET AND SOCIAL VALUES FOR FARMS

9.1.1: TRUNCATION OF IMAGES

An initial attempt to implement our methodology revealed that the range of certain environmental variables across the full extent of the study area was considerably greater than that of our sample farms. This was most noticeable amongst our milk farm sample which lacked sufficient upland observations. In general there was not a problem across the vast majority of our study area which is in agricultural use. Rather it was at the extremes, particularly in very mountainous areas that in effect we are attempting to predict outside the range of available data[42].

An analysis was undertaken to assess the extent of this problem. Table 9.12 details descriptive statistics for each of the environmental variables used in our models. Distributions are given for variation across the entire study area (the all-Wales image; rows W), and for the corresponding variable in the sheep sample, (rows S) and milk sample (rows M).

Analysis of table 9.12 reveals that there are a number of problems with extreme values. In effect two solutions are feasible for such a problem (Altman and Gardner, 1989): either we can refrain from prediction in such areas or we can truncate each environmental variable to some level represented in our farm sample data. The latter course of action was preferred as it was felt that having holes in the final map of predicted values would be confusing. Affected cells were set to the upper or lower limit of the farm sample data as appropriate. This does mean that we have less confidence in our predictions for affected areas. However, the analysis summarised in tables 9.13 and 9.14 shows that relatively few cells are affected by this problem.

[41]Note that this ignores the externalities not included in our analysis e.g. any social benefits of maintaining sheep farmers in employment.

[42]Altman and Gardner (1989; p.36) present a statistical perspective upon this problem.

Table 9.12: Descriptive statistics for environmental variables across entire study area and within farm sectors.

The order within variables is (vertically): 1. All Wales image (W)
2. Milk farms (M)
3. Sheep farms (S)

Labels defined in chapter 7. Blank entries signify that the variable was not used for the farms in question.

Variable	N	Mean	Median	TrMean	StDev	SEMean	Min	Max	Q1	Q3	Min Ratio	Max Ratio
W AWcer^2	20563	21566	14400	18752	18717	131	4900	122500	13225	19600		
M AWcer^2	104	15702	14400	15277	3714	364	9025*	30625*	13225	18158	1.842	4.000
S												
W AWgra^2	20563	21252	15625	18748	17210	120	4900	115600	13225	19600		
M AWgra^2	104	15991	14400	15419	4121	404	7225*	34225*	14400	16900	1.474	3.378
S												
W Elev^2	20563	68004	38809	58708	80506	561	1	902500	9216	97344		
M Elev^2	104	33791	15912	29908	39094	3833	100	191844*	4492	50963	-	4.704
S												
W Enddry	20563	125.71	117.00	123.28	28.07	0.20	81.00	244.00	106.00	134.00		
M Enddry	104	109.15	107.00	108.30	14.55	1.43	85.00	185.00*	99.00	117.00	1.049	1.319
S												
W Enddry^2	20563	16592	13689	15679	8250	58	6561	59536	11236	17956		
M Enddry^2	104	12124	11449	11827	3567	350	7225	34225*	9801	13689	1.101	1.740
S												
W Endwet	20563	173.88	176.00	173.93	18.11	0.13	126.00	243.00	160.00	188.00		
M												
S Endwet	85	170.33	167.00	169.78	18.11	1.96	133.00	219.00*	157.00	185.00	1.055	1.110
W Grazseas	20563	150.00	160.00	153.25	65.18	0.45	-96.00	251.00	107.00	204.00		
M Grazseas	104	192.67	199.00	195.22	36.36	3.57	44.00*	249.00	181.00	217.00	2.180	1.008
S												
W lnAWpot	20563	4.7856	4.7449	4.7687	0.2106	0.0015	4.2485	5.5984	4.6540	4.7875		
M lnAWpot	104	4.6925	4.6540	4.6843	0.1013	0.0099	4.2485	5.0752*	4.6540	4.7449	1.000	1.103
S												
W lnEwet	20563	5.1529	5.1705	5.1550	0.1057	0.0007	4.8363	5.4931	5.0752	5.2364		
M lnEwet	104	5.0885	5.0814	5.0905	0.1079	0.0106	4.8363	5.2781*	4.9989	5.1761	1.000	1.041
S												

Table 9.12 (cont.)

Variable	N	Mean	Median	TrMean	StDev	SEMean	Min	Max	Q1	Q3	Min Ratio	Max Ratio
W lnFCdays	20563	5.5732	5.5607	5.5754	0.2010	0.0014	5.0626	5.8999	5.4161	5.7268		
M												
S lnFCdays	85	5.5338	5.4931	5.5311	0.1951	0.0212	5.1705	5.8999	5.3822	5.6454	1.021	1.000
W lnSlope	20563	0.63575	0.93216	0.75754	1.28544	0.00896	-4.60517	3.14974	0.19062	1.46787		
M lnSlope	104	0.5339	0.6497	0.6086	0.9926	0.0973	-3.2189*	2.4824*	0.0770	1.1402	1.431	1.269
S lnSlope	85	0.6909	0.8154	0.7031	0.8474	0.0919	-1.6607*	2.3224*	0.1310	1.3749	2.773	1.356
W MdefCerl	20563	37.088	37.000	36.394	25.239	0.176	0.000	108.000	16.000	56.000		
M MdefCerl	104	55.22	54.50	55.61	22.64	2.22	2.00	108.00	37.00	74.00	-	1.000
S												
W Rain^2	20563	2113536	1690000	1939507	1504287	10490	422500	15476356	1151329	2566404		
M Rain^2	104	1335633	1185922	1295271	626473	61431	422500	3876961*	797927	1765183	1.000	3.992
S												
W Reg456	20563	0.49438	0.00000	0.49376	0.49998	0.00349	0.00000	1.00000	0.00000	1.00000		
M Reg456	104	0.7692	1.0000	0.7979	0.4234	0.0415	0.0000	1.0000	1.0000	1.0000	1.000	1.000
S												
W sinAsp	20563	-0.00657	-0.01745	-0.00730	0.69060	0.00482	-1.00000	1.00000	-0.68202	0.66914		
M sinAsp	104	-0.0363	-0.0785	-0.0399	0.7336	0.0719	-1.0000	0.9998	-0.7660	0.7518	1.000	1.000
S												
W SprMWD	20563	1.2926	0.0000	0.7978	2.9523	0.0206	0.0000	25.0000	0.0000	1.0000		
M SprMWD	104	2.106	0.000	1.638	3.694	0.362	0.000	15.000*	0.000	3.000	1.000	1.667
S SprMWD	85	1.153	0.000	0.597	2.958	0.321	0.000	14.000*	0.000	1.000	1.000	1.786
W SprMWD^2	20563	10.387	0.000	3.828	35.572	0.248	0.000	625.000	0.000	1.000		
M												
S SprMWD^2	85	9.98	0.00	2.18	36.91	4.00	0.00	196.00*	0.00	1.00	1.000	3.189

For minima * signifies that the minimum value from the all-Wales image lies more that 1sd (farm) below the minimum for the farm dataset indicated.

For maxima * signifies that the maximum value from the all-Wales image lies more that 1sd (farm) below the maximum for the farm dataset indicated.

Min ratio is calculated as (Minimum Farm Value / Minimum All-Wales Value) except where one or more of these is negative where the ratio is then calculated as (Minimum All-Wales Value / Minimum Farm Value)

Max ratio is calculated as (Maximum All-Wales Value / Maximum Farm Value)

Table 9.13 details for our sheep farm analysis the number of cells in which environmental variables on the all-Wales GIS image were set to either the upper or lower limit of the same variable in the sheep farm sample. Table 9.14 repeats this analysis for milk farms.

Table 9.13: Number of cells truncated in prediction of sheep farm values

Variable[1]	Cells truncated to lower value		Cells truncated to upper value	
	No. of cells	% of all cells[2]	No. of cells	% of all cells[2]
lnFCdays	272	1.32	-	-
SprMWD	-	-	138	0.67
Endwet	97	0.47	150	0.73
lnSlope	1262	6.14	400	1.95

Notes: 1. Square truncated to the same degree as untransformed variables.
2. There are 20563 1km square land cells.

Table 9.14: Number of cells truncated in prediction of milk farm values

Variable			Cells truncated to upper values	
	No. of cells	% of all cells[1]	No. of cells	% of all cells[1]
lnEwet	-	-	2149	10.45
Enddry	16	0.08	1400	6.81
AWcer^2	200	0.97	2597	12.63
SprMWD	-	-	106	0.52
Rain^2	-	-	2100	10.21
MdefCerl	2084	10.13	-	-
Grazseas	1428	6.94	56	0.27
Elev^2	290	1.41	1544	7.51

Notes: 1. There are 20563 1km square land cells.

It is likely that the majority of truncations will occur in a relatively small number of cells.. To test this the number of truncated variables in each land cell was calculated. Results from this analysis are presented in table 9.15.

Table 9.15: Number of truncated variables in each 1km square cell

Number of truncated variables	Sheep farm analysis		Milk farm analysis	
	No. of cells	% of all cells	No. of cells	% of all cell
0	18,526	90.09	15,303	74.42
1	1,663	7.94	2,088	10.15
2	26	0.13	772	3.75
3	168	0.82	515	2.50
4	98	0.48	337	1.64
5	20	0.10	377	1.83
6	8	0.04	396	1.93
7	52	0.25	323	1.57
8	2	0.01	313	1.52
9	0	0.00	139	0.68
10	0	0.00	0	0.00

Consideration of table 9.15 shows that the effects of truncation upon our predictions of sheep farm value are relatively trivial. This is less true of our analysis of milk farms where around 10% of cells for certain variables are affected. The reason for this difference is simple, namely that there are relatively few milk farms in extreme upland areas. Consequently we have to be circumspect about our predictions of milk farm values in such upland areas.

9.9.2: PREDICTING FARM SURPLUS

Farm Surplus values were now estimated by running the various stage 2 models (using truncated environmental variable surfaces as appropriate) to predict the input variables for the stage 1 models from which Farm Surplus values were then estimated. (Appendix 7.5 details the batch files used in this operation.) Table 9.16 details these values for both sectors (as these are annual figures discounting is not an issue here).

Table 9.16: Predicted Farm Surplus values for sheep and milk farms

Farm Surplus (£/ha)	Sheep farms		Milk farms	
	No. of cells	% of all cells[1]	No. of cells	% of all cells[1]
0.00 to 49.99	2483	12.08	7	0.03
50.00 to 99.99	6346	30.86	37	0.18
100.00 to 149.99	9492	46.16	248	1.21
150.00 to 199.99	1728	8.40	463	2.25
200.00 to 249.99	323	1.57	825	4.01
250.00 to 299.99	191	0.93	261	1.27
300.00 to 349.99	-	-	274	1.33
350.00 to 399.99	-	-	317	1.54
400.00 to 449.99	-	-	307	1.49
450.00 to 499.99	-	-	500	2.43
500.00 to 549.99	-	-	1295	6.30
550.00 to 599.99	-	-	2342	11.39
600.00 to 649.99	-	-	4845	23.56
650.00 to 699.99	-	-	5067	24.64
700.00 to 749.99	-	-	3171	15.42
750.00 to 799.99	-	-	543	2.64
800.00 to 849.99	-	-	61	0.30

Note: 1. There are 20563 1km square land cells.

Table 9.16 underlies the highly significant difference in profitability between the two sectors. This difference becomes more extreme if we recall that there are relatively fewer milk than sheep farm in areas of environmental adversity, i.e. those cells at the lower end of the distribution of predicted Farm Surplus probably refer to very few (if any) real world milk farms.

Our adjustment factors were then applied as detailed previously to estimate our focus values of FGI and SV.

9.9.3: PREDICTING FGI AND SV

By applying the adjustment factors ADJFGIS and SVadjs to the estimates of Farm Surplus for sheep farms we obtain the objective of our study of this sector; the predicted market and social values of such farms. Figure 9.3 illustrates the GIS image for FGIs while figure 9.4 illustrates SVs.

The distribution of predicted values of FGIs and SVs is similar and conforms strongly to prior expectations. Values are lowest in the Snowdonia, Cambrian and Brecon mountains and increase as we move into lowland areas. Localised variation due to soil quality and related impacts can also be detected. The overall picture seems highly plausible. We can now repeat this analysis for our milk farm sample. Figure 9.5 illustrates the GIS image for FGIm while figure 9.6 details SVm.

As both the adjustment factors ADJFGIM and SVadjm are constants applied to predicted Farm Surplus values, the maps of FGIm and SVm only differ in terms of absolute values. For both we can see strong topographic and soil effects (see for example the band of poorer soils extending down the centre of the Pembroke peninsula). As before the predicted values conform strongly to prior expectations.

Comparing figures 9.3 to 9.6 we can see that for each sector social values lie substantially below farm gate income levels. However, the most stark contrast is between sectors, with milk values very much higher than their sheep equivalents. Table 9.17 details this contrast by reporting frequency distributions for all four variables.

Table 9.17: Predicted farm gate income and social values for sheep and milk farms ($1km^2$ cells)

Value (£/ha)	Sheep farms				Milk farms			
	FGIs		SVs		FGIm		SVm	
	No. of cells	% of all cells[1]	No. of cells	% of all cells[1]	No. of cells	% of all cells[1]	No. of cells	% of all cells[1]
-100.00 to -50.01	-	-	-	-	3	0.01	-	-
-50.00 to -0.01	-	-	-	-	37	0.18	-	-
0.00 to 49.99	-	-	7,414	36.06	219	1.07	32	0.16
50.00 to 99.99	-	-	12,389	60.25	418	2.03	364	1.77
100.00 to 149.99	8,296	40.34	728	3.54	887	4.31	1,184	5.76
150.00 to 199.99	11,506	55.95	32	0.16	264	1.28	452	2.20
200.00 to 249.99	527	2.56	-	-	251	1.22	468	2.28
250.00 to 299.99	234	1.14	-	-	336	1.63	734	3.57
300.00 to 349.99	-	-	-	-	284	1.38	2,640	12.84
350.00 to 399.99	-	-	-	-	479	2.33	7,510	36.52
400.00 to 449.99	-	-	-	-	1,186	5.77	6,566	31.93
450.00 to 499.99	-	-	-	-	2,231	10.85	613	2.98
500.00 to 549.99	-	-	-	-	4,582	22.28	-	-
550.00 to 599.99	-	-	-	-	5,228	25.42	-	-
600.00 to 649.99	-	-	-	-	3,467	16.86	-	-
650.00 to 699.99	-	-	-	-	608	2.96	-	-
700.00 to 749.99	-	-	-	-	83	0.40	-	-

Note: 1. There are 20563 1km square land cells.

Figure 9.3: Predicted farm gate income for sheep farms (FGIs) (£/ha, 1990)

Farm Gate Income for Sheep Farming, (£/ha/year)

100 to 149 | 150 to 199 | 200 to 299

Figure 9.4: Predicted social value for sheep farms (SVs) (£/ha, 1990)

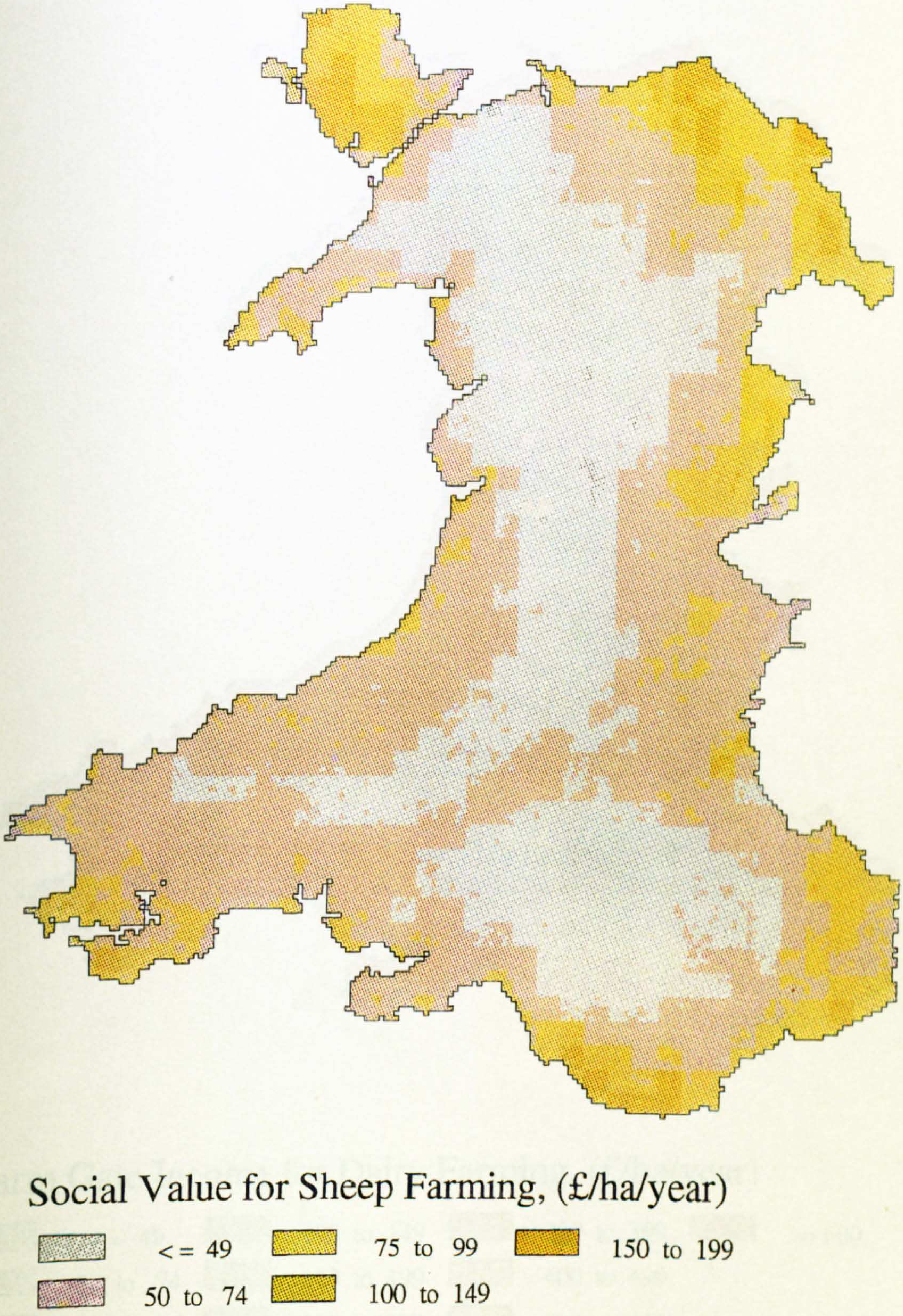


Figure 9.5: Predicted farm gate income for milk farms (FGIm) (£/ha, 1990)

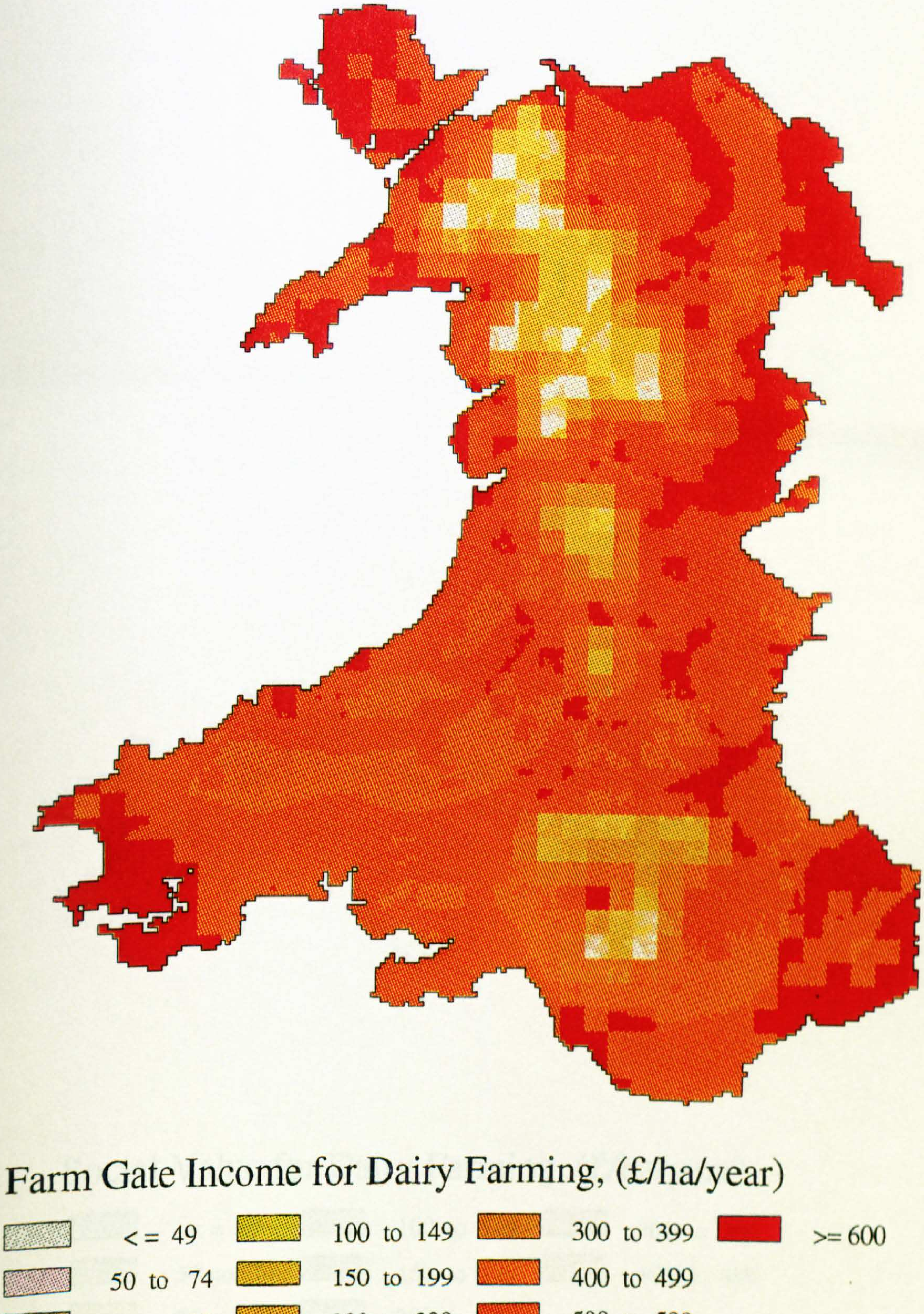


Figure 9.6: Predicted social value for milk farms (SVm) (£/ha, 1990)

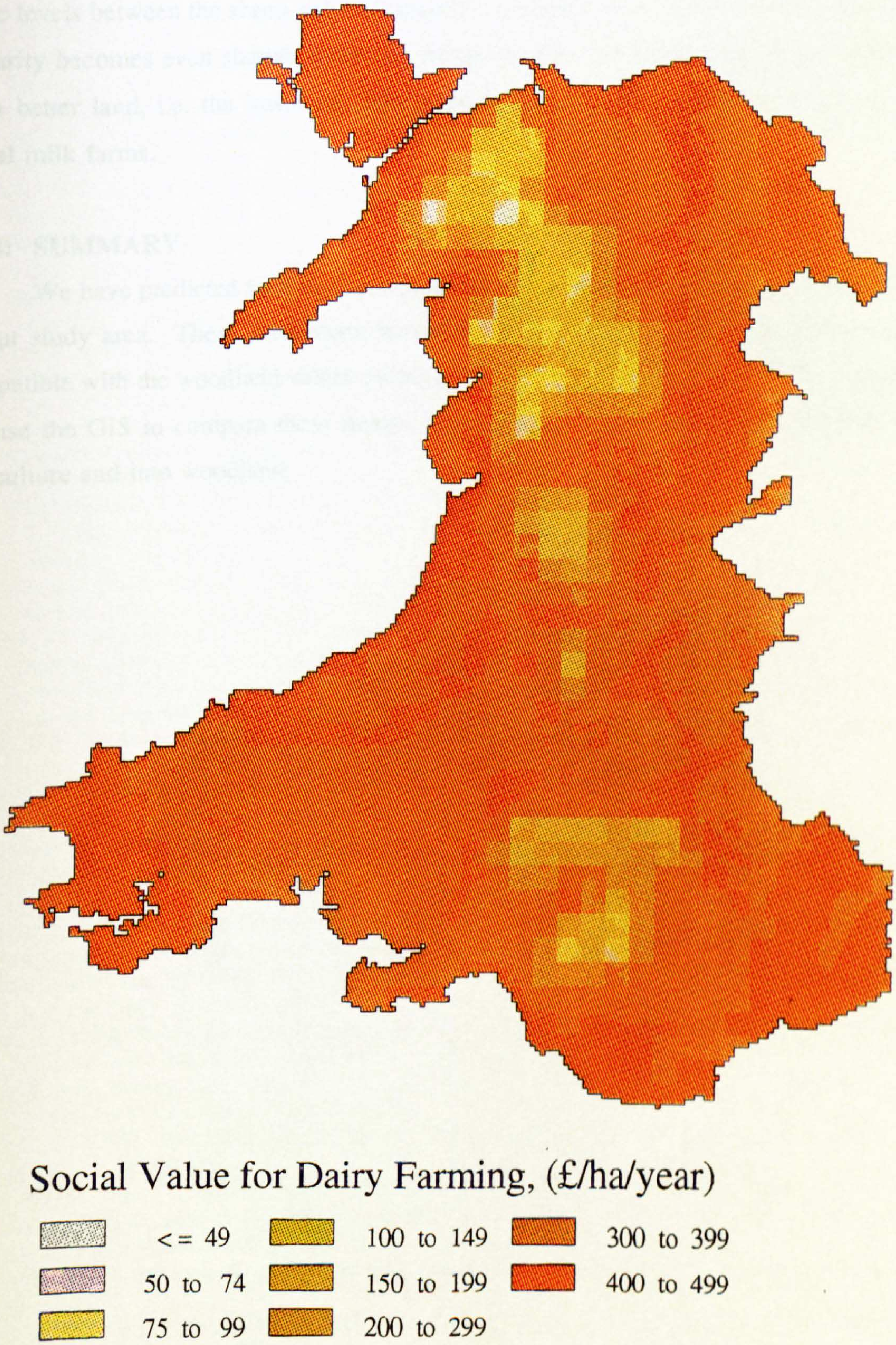


Table 9.17 quantifies the very wide disparity in both farm gate income and social value levels between the sheep and milk sectors. As noted with respect to Farm Surplus, this disparity becomes even sharper when we recognise that milk farms tend to be concentrated upon better land, i.e. the lower say 10% of milk values will, in reality, contain very few actual milk farms.

9.9.4: SUMMARY

We have predicted both market and social values of the two major agricultural sectors of our study area. These predictions have been produced in a GIS image format which is compatible with the woodland values estimated in previous chapters. In the following chapter we use the GIS to compare these images and evaluate the net benefits of transfers out of agriculture and into woodland.

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SECTION C: COMPARISON OF FORESTRY AND AGRICULTURE

Chapter 10: Cost Benefit Analysis

10.1: INTRODUCTION

In this chapter we assess the net benefits of converting land out of agriculture and into woodland. This assessment is made from a number of standpoints. We have considered two types of agriculture (sheep and milk) both assessed in two ways (market and social valuation), and two species of tree (conifer, represented by Sitka spruce; and broadleaf, represented by beech). Furthermore, we have assessed a variety of woodland benefits (recreation, timber and carbon sequestration), which allows us to consider a succession of definitions of what in economic terms constitutes a woodland. Finally wherever there has been a time dimension (namely in our analysis of timber yield and carbon sequestration) we have made our assessment using a variety of discount rates.

The results presented here consider the full range of permutations discussed above. In essence each analysis takes a specific farm type (say sheep farming) and subtracts successive definitions of woodland benefits (say timber and carbon storage) assessed at a given discount rate (say 6%). Here a negative sum indicates that woodland benefits outstrip those of agriculture and vice versa for positive sums. These various net benefit value estimates are devised directly from the GIS by overlaying the respective images and adding or subtracting values as necessary. Comparison of net benefit values of conversing between sheep farming and woodland, and between dairy farming and woodland also allows us to calculate values for potential conversions between the sheep and dairy sectors.

An important caveat to all these calculations concerns the extent to which woodland benefits are additive. The maps of timber value created in chapter 7 implicitly assume that the expansion of supply generated by any new planting would have no net impact upon the price of timber. Given that the vast majority of the timber consumed in the UK is imported and that the price is in effect fixed on the world market, then this seems a reasonable assumption. Similarly the maps of carbon sequestration value presented in chapter 8 assume that the extra carbon stored by any new planting would have a negligible effect upon the unit value of carbon storage. Again, given the minuscule proportion of excess atmospheric carbon which would be removed by such afforestation, this seems a very reasonable assumption. However, we cannot extend this line of reasoning to the recreation value maps created in chapter 5. Here any substantial increase in the supply of recreational sites is liable to impact upon any excess demand[1] such that the value of any further sites is diminished. In effect, as the number of sites increase so the marginal implicit price of woodlands recreation falls.

To allow for this we add woodland benefits in the following order. Firstly agricultural values are assessed against timber values alone. This analysis includes the various forest grants and subsidies available to farmers (assessed as per chapter 7) net of incurred planting and maintenance costs. When assessed from the point of view of the farmers (rather than from society's standpoint) this is in effect mimicking the present day decision facing farmers. This provides a useful cross-check point between our valuation estimates and the real world.

The second analysis adds carbon values to those derived from timber and re-assesses the net benefits of conversion from agriculture. Finally, the third stage of analysis adds in recreational values and recalculates conversion net benefits. However, here we have to recognise the substitution effect outlined above. Because of this we cannot have confidence in the overall value sum created by such a calculation. Rather we can use this stage to identify those areas which would generate the very highest net benefits from conversion. This of itself is a highly useful result given that, in reality resources limits mean that only a finite, and probably relatively small, amount of funds will be available to support conversion. Using the analysis outlined here allows the identification of prime sites for conversion. These calculations are then repeated from society's standpoint to create the social value equivalent of each of the above sums.

10.2: RESULTS

Results are categorised by the various discount rate, woodland species and farm sector under consideration. We begin by holding the discount rate and woodland species constant and examine results by farm sector. We then vary the tree species and finally change discount rate to present a full sensitivity analysis.

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[1]Indeed given the existence of a number of recreational forests within the study area, our estimates of recreational value may already be too high. However, the work of Willis and Benson (1989), as reviewed in Appendix 1, suggests this is not the case and that our estimates are quite reasonable and may even be lower bound values. Nevertheless, this uncertainly is unsatisfactory and one of the first extensions we propose to undertake is an incorporation of data on existing land use (including the present availability of woodland) from the ITE Land Use Database, the Bartholomew's Database and other sources.

10.2.1: RESULTS FOR THE 6% DISCOUNT RATE

In this section we hold the discount rate at 6% (exponential) throughout. This is a useful initial level to use for the calculation of social values as it is the current Government rate for socially beneficial projects, although our analyses of rates of return (chapter 6) suggests that it is somewhat higher than commonly used on sheep farms although it may be representative of rates used on some milk farms. We begin our discussion of results by considering potential conversions to conifer woodland.

10.2.1.1: Conversion to conifer woodland

We begin this section by presenting results for conversion from sheep farms, subsequently turning our attention to the milk farm sector.

Sheep farms

Table 10.1 reports results from one full run of our cost-benefit model holding the discount rate at 6% and analysing the net benefits of conversion from sheep farming into conifer woodland.

The first two columns of table 10.1 contain value interval limits in £/ha per annum. The remainder of the table consists of two blocks of four columns each, the first of which detail farm gate values while the second details social value equivalents. For both blocks the four columns refer to successively wider definitions of woodland benefits. The first column considers only the timber value while the second adds in carbon sequestration values. This is supplemented by recreation values in the third and fourth column, the former of which uses a lower bound recreation value (derived from the contingent valuation (CV) cross-study "meta-analysis" detailed in chapter 5) while the latter uses an upper bound value (derived from our individual travel cost method (ITCM) analysis, also detailed in chapter 5)[2].

[2]The CV meta-analysis derived a mean value of £1.82/party visit and forms the basis of the predicted recreation image for Wales illustrated as panel D of figure 5.10. The image created from our ITCM study, which derived a mean value of £3.59/party visit, is illustrated in panel B of the figure. These values are somewhat lower, although comparable than those estimated for the study area by Willis and Benson (1989). The site based values of figure 5.10 were converted to per hectare equivalents by dividing through by a mean site area of 4,000 hectares (pers. comm., Anna Chylack, Forestry Commission, 1994; and Willis and Benson, 1989). The resulting values are within the range quoted by Benson and Willis (1993).

Table 10.1: Distribution of the net benefits of retaining sheep farming in Wales as opposed to conversion to conifer woodland[1]: 6% discount rate (£/ha/yr: 1990)

Tree species →		Sitka spruce							
Agricultural values →		Farm gate values				Social values			
Woodland values[2] →		timber only (sfg-s6ta)	timber+ carbon (sfg-s6za)	timber+ carbon+ recreation (CVM) (sfg-s6zc)	timber+ carbon+ recreation (ITCM) (sfg-s6zt)	timber only (sso-s6ta)	timber+ carbon (sso-s6za)	timber+ carbon+ recreation (CVM) (sso-s6zc)	timber+ carbon+ recreation (ITCM) (sso-s6zt)
Lower Limit (£/ha/yr)	Upper Limit (£/ha/yr)								
-475.00	-450.01								24
-450.00	-425.01								35
-425.00	-400.01								132
-400.00	-375.01								122
-375.00	-350.01				25				274
-350.00	-325.01				99				220
-325.00	-300.01				90			117	610
-300.00	-275.01				133			213	1004
-275.00	-250.01				232			474	1472
-250.00	-225.01			9	285			1687	3153
-225.00	-200.01			153	737		284	5121	6478
-200.00	-175.01			266	1131		7136	7671	4346
-175.00	-150.01			599	1582		8292	3446	1639
-150.00	-125.01		5	2097	3617	7	3446	1081	427
-125.00	-100.01		899	5852	6153	771	757	208	111
-100.00	-75.01		8286	6612	3849	10540	125	40	21
-75.00	-50.01		6895	3005	1459	7438	27	15	6
-50.00	-25.01	18	2840	1074	467	1486	6	1	0
-25.00	-0.01	1978	809	272	164	296	1	0	0
0.00	24.99	10811	248	117	46	24	0	0	0
25.00	49.99	5929	84	17	5	1	0	0	0
50.00	74.99	1287	7	1	1		0	0	0
75.00	99.99	323	1	0	0		0	0	0
100.00	124.99	188	0	0	0		0	0	0
125.00	149.99	29	0	0	0		0	0	0
150.00	174.99		0	0	0		0	0	0
175.00	199.99		0	0	0		0	0	0
200.00	224.99		0	0	0		0	0	0
225.00	249.99		0	0	0		0	0	10
250.00	274.99		0	0	0		3	29	92
275.00	299.99		0	0	0		64	146	210
300.00	324.99		0	0	0		236	263	164
325.00	349.99		0	4	20		177	48	13
350.00	374.99		11	28	87		9	3	
375.00	399.99		57	142	199				
400.00	424.99		228	249	160				
425.00	449.99		181	62	23				
450.00	474.99		12	4					

Notes: 1. Negative sums indicate areas where woodland values exceed agricultural values.
Blank cells indicate that no 1km squares fall into this category. There are 20563 1km square cells.
2. Labels in brackets are image filenames.

The first column of the farm gate values block indicates the net benefit to farmers of converting out of sheep farming and into woodland under the present regime of grants and subsidies (image sfg-s6ta). Here negative values show situations where these woodland benefits outstrip the present sheep values. As can be seen, in the vast majority of cases (over 90% of cells) the benefits to farmers of staying in sheep agriculture exceed the benefits of converting into woodland. However, this difference is relatively marginal with the net benefit of remaining in agriculture being, in almost all cases, less than £100/ha and with almost 10% of cells showing a small net benefit from conversion[3].

Nevertheless the clear picture is that when we consider farmers perceptions of income then, under present levels of woodland grants and subsides, this analysis predicts very little conversion out of even sheep agriculture into woodland in the study area. This is indeed the situation on the ground with sources at both MAFF (Fearn, 1990) and the Forestry Commission (pers. comm. Adrian Whiteman, 1994) suggesting that insignificant numbers of Welsh farms have entered forestry schemes to date.

Does this result provide validation for our estimates? As indicated the 6% discount rate used here is somewhat higher than we would expect sheep farmers to use in their everyday decision making, yet it produces a result which is consistent with observed behaviour. There are a number of persuasive reasons explaining this result. These centre around the common observation that decision makers in almost any field (and notably agriculture) demand a premium from risky or unfamiliar investments. Such diversification brings inherent uncertainty for the farmer regarding the levels of labour, capital, skill and entrepreneurship which will be required as well as uncertainty regarding the ultimate returns from such an enterprise. This is particularly true of forestry which for the farmer is both very different from the well known patterns of sheep production and involves a time scale which is an order of magnitude different to any of the decisions he/she usually encounters.

Cobb (1993) reviews a number of studies of agricultural risk premiums and reports on his own large sample survey of UK farmers which revealed that such farmers required very substantial increases in gross margin before they would consider conversion into low input extensification options such as that promoted under the Countryside Stewardship

[3]Note that it is at the extremes that the truncation effect discussed in chapter 9 will apply. These will tend to mask the lowest agricultural values and so conversion could be beneficial in somewhat more than 10% of cases although this error will be minor (particularly with respect to sheep farms).

Scheme. Cobb feels that this is primarily due to a preference by farmers to retain familiar activities and agricultural technique and apprehension regarding what are now unfamiliar farming techniques[4]. Our own research (Bateman et al., 1996) shows that this is also the case with respect to conversions out of conventional agriculture and into woodland. Here minimum increases in profit rates of up to 100% were required before agreement to convert was forthcoming. Lloyd et al. (1995)[5] suggest that one reason for this may be the perception by farmers, fostered by the long commitment period of grant schemes and the requirement for replanting as a proviso in the granting of felling orders[6], that conversions to woodland may be irreversible[7].

The risk premiums associated with such conversions can be modelled in a number of ways, one of which is to apply a higher discount rate than that normally used for standard investments. That is in effect precisely what is being done in the farm gate values block of table 10.1 and we can see that once this is done our model produces in the first column of this block a result which very closely resembles what is observed in the real world, we return to this theme subsequently (see discussion of table 10.5 below).

Given that we now have support from the real world for the predictions of our model, this first column also provides useful indications of the responsiveness of sheep farmers to increases in the level of timber grants and subsidies. Our results suggest that even a modest increase in the real level of such subsidies may produce significant increases in the financial viability of conversion. Given that the higher discount rate used here implicitly takes into account farmers risk aversion, then we might expect this to translate into actual conversions. Over 50% of the cells show and excess of sheep values over timber woodland values of less than £25/ha/yr. This suggests that while subsidies are currently too low to be effective, substantial conversions may be induced from modest increases in these subsidies.

While the results shown in table 10.1 are of interest, the GIS images from which they are derived are more informative (although less easy to summarise). Figure 10.1 illustrates

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[4]Another interesting possibility explaining negligible conversion rates is explored by Saarinen (1966) who, in a study of US farmers who would, on purely financial grounds, have been better off by giving up a specific type of farming, found a consistent over-optimism about future performance which persisted across long time series. However, he did identify a subset of innovative farmers who were receptive to the possibility of diversification.

[5]See also Williams et al. (1994) which gives further details regarding this study.

[6]See our discussions with the Forestry Commission mentioned in chapter 7.

[7]This may also adversely affect land prices.

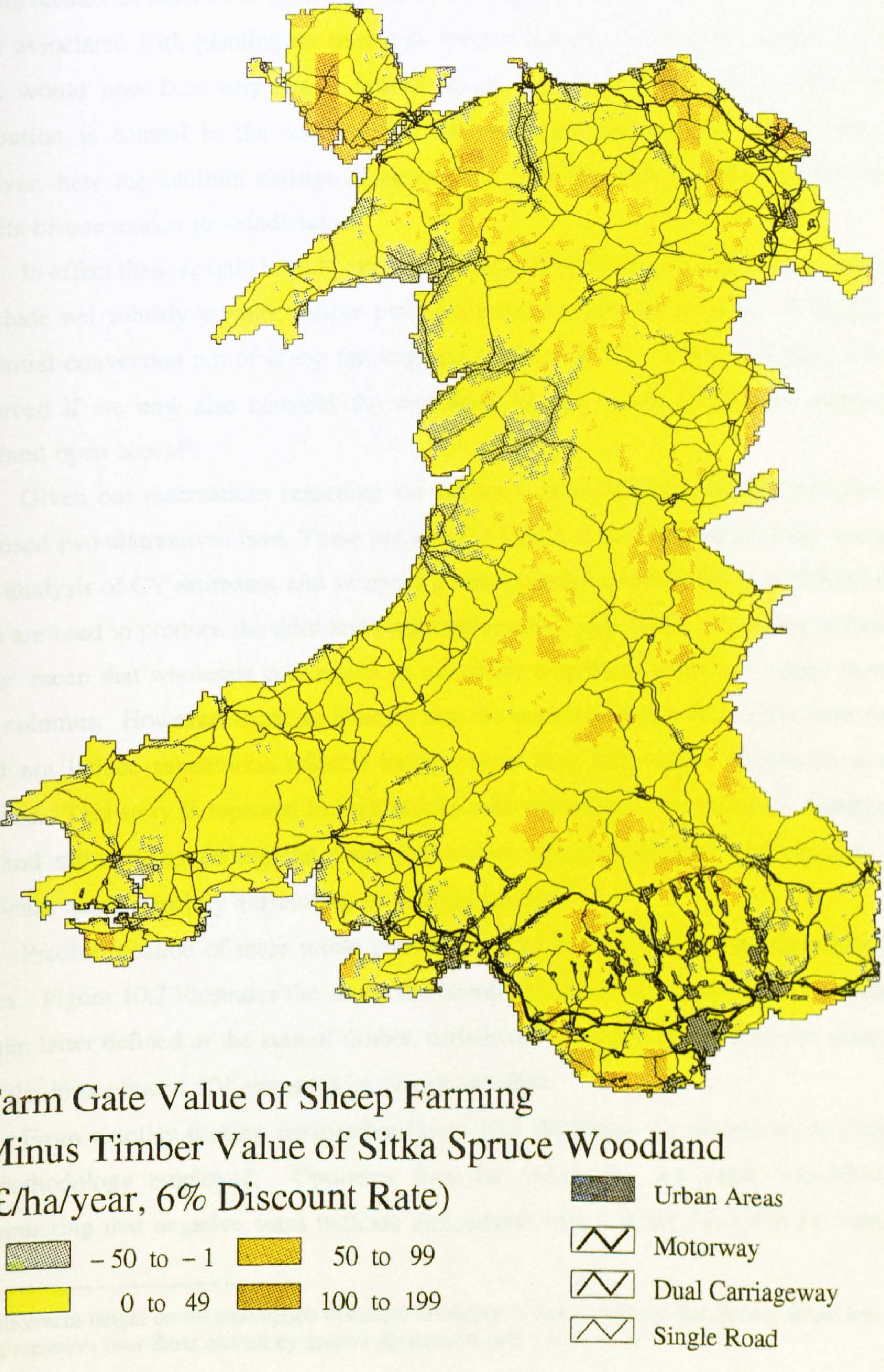
the GIS image which underpins our farm gate valuation of the conversion from sheep farming to woodland under present subsidy levels. As can be seen the majority of areas produce positive differences between sheep farming and timber i.e. under present circumstances and if we only consider the market priced benefits of forestry (timber and grants), then farm gate income is generally higher under sheep than under woodland. However, the image does show certain mainly lowland, valley floor areas, where negative figures are recorded indicating that the income farmers could receive from timber and related grants is marginally higher than that of sheep rearing. It is the marginal nature of this advantage which probably provides the best explanation of why such conversions have not in practice generally taken place.

The social value equivalent of the above analysis is given in the first column of the second block of table 10.1 (image sso-s6ta). The transfer savings created by a move out of sheep into the relatively less subsidised production of timber means that the social net benefits of such conversion are significantly higher than their farm gate equivalents. This difference is most noticeable here where very nearly 100% of cells record negative values i.e. even when we only include timber benefits, the social value of woodland exceeds that of sheep production. This result is all the more powerful when we recall that the 6% discount rate used here is the same as that used by the UK Government for such calculations.

Comparison of the first columns in both blocks is revealing. While a conversion out of sheep and into woodland is unattractive from the farm gate, it generates net benefits from society's point of view. The potential clearly exists for a win/win bargain in which society pays some of its subsidy savings back to farmers as compensation for lost income so that each side benefits. Given that the magnitude of social benefits is similar to that of farm loss, such a compensation scheme would, on these figures need to be carefully constructed. However, once we widen our definition of woodland benefits the case for compensation become much more clear cut.

The second column of each block adds in net carbon sequestration values to the benefits of woodland. In the case of the farm gate values we are in effect modelling the impact of assigning to farmers the net carbon flux value associated with planting trees on their land. In the general case where such planting causes an increase in carbon storage we credit farmers with these values as a hypothetical subsidy. In the more rare case of planting on peat soils, farmers are now debited with a hypothetical charge against the farm account equivalent to the value of carbon liberated.

Figure 10.1: The farm gate net benefit of retaining sheep farming as opposed to conversion to conifer woodland (defined as timber plus grants only, i.e. present situation): 6% discount rate (£/ha/yr: 1990)



The impact of this expanded definition of woodland values is highly significant, moving the vast majority of farms (over 95%) to a situation where conversion from sheep farming creates an increase in farm gate income (image sfg-s6za). However, the large carbon losses associated with planting on peat now means that there is a small number of farms which would now face very heavy overall losses from such conversion. This bimodal distribution is echoed in the social value equipment of this analysis (image sso-s6za). However, here the addition savings of agricultural subsidies substantially increase the net benefits of conversion to woodland.

In effect then we only have to expand our definition of the social benefits of woodland to include net subsidy savings, timber production and carbon sequestration to justify very substantial conversion out of sheep farming and into woodland. This conclusion is further reinforced if we now also consider the recreation benefit values created by making that woodland open access[8].

Given our reservations regarding the accuracy of recreational benefit measures, we have used two alternatives here. These are a lower bound estimate obtained from our cross-study analysis of CV estimates, and an upper bound measure obtained from our ITCM study. These are used to produce the third and fourth columns of each block. As noted substitution effects mean that wholesale conversion to woodland would not attain the values shown in these columns. However, these do indicate that the conversion of a few select sites (which would not induce substitution effects) would create very high value woodlands in those locations. This story is repeated in both blocks with the social value columns (images sso-s6za and sso-s6zt) exceeding the farm gate values (images sfg-s6zc and sfg-s6zt) by a significant amount mainly attributable to subsidy savings.

Precise location of these prime conversion sites is facilitated by inspection of these images. Figure 10.2 illustrates the social net benefit of conversion from sheep to woodland with the latter defined as the sum of timber, carbon storage and recreation values (measured using the lower bound CV estimate) i.e. image sso-s6zc.

From a policy making perspective figure 10.2 illustrates the interpretative clarity of the methodology employed. Optimum sites for conversion are easily identified and (remembering that negative sums indicate agricultural values being exceeded by woodland

[8]This statement hinges on the assumption discussed in chapter 5, that woodland recreational values are surplus measures over those created by general agricultural land use.

benefits) corresponding estimates of the monetary net benefit of such conversion is given. However, while this map is readily interpretable its message throws a critical light over past policy decisions. As figure 10.2 clearly shows, the prime sites for conversion are located in lowland areas (with high timber productivity and carbon storage) and near to centres of high population and accessibility (yielding high recreation values)[9]. This is particularly noticeable in South Wales where the urban centres of Cardiff and Swansea, augmented by the infrastructure effect of the M4, result in very high recreational values in addition to the excellent timber yields and consequent carbon sequestration levels engendered by these lowland areas. Conversely conversion is least justified in uplands areas and most noticeably upon peat soils where our analysis shows that retention within agriculture is clearly preferable.

This result seems eminently sensible and accords with the sentiment made popular in the 1980's that policy makers should "bring forests down the hill". However, as this slogan indicates, in general actual planting decisions have been almost completely at odds with this logic. Rather than the recreational needs of the majority lowland urban populace being recognised, forests have in the main been planted in inaccessible upland areas - quite the reverse of that advocated in figure 10.2. This policy seems to have been led by a desire to reduce the land purchase costs of planting trees, in ignorance of the economic value of such a strategy.

Milk farms

A second complete run of the model is presented in table 10.2 which maintains the woodland species as conifer and holds the discount rate at 6% but now considers potential conversions out of milk production. To allow further comparison with previous results, figure 10.3 illustrates the image for the farm gate value of converting out of milk production into conifer woodland when only timber values are considered (i.e. the present day decision facing milk farmers; image mfg-s6ta), while figure 10.4 details the social value of conversion when the broad definition of woodland (timber, carbon storage and recreation with the latter again measured using our CV cross-study value) is used (image mso-s6zc).

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[9]There is a fascinating comparison here with the prescriptions of von Thunen's (1826) *Isolerte Staat* and subsequent land use analysis. For example Haggett et al. (1977, p.206) note (without the benefit of specific analysis) that although financially non-viable, "in highly urbanized areas the demand for 'recreational' wooded areas may sometimes lead to its persistence in areas of high accessibility".

Figure 10.2: The social net benefit of retaining sheep farming as opposed to conversion to conifer woodland (defined as timber, carbon storage and recreation; the latter measured using contingent valuation): 6% discount rate (£/ha/yr: 1990)

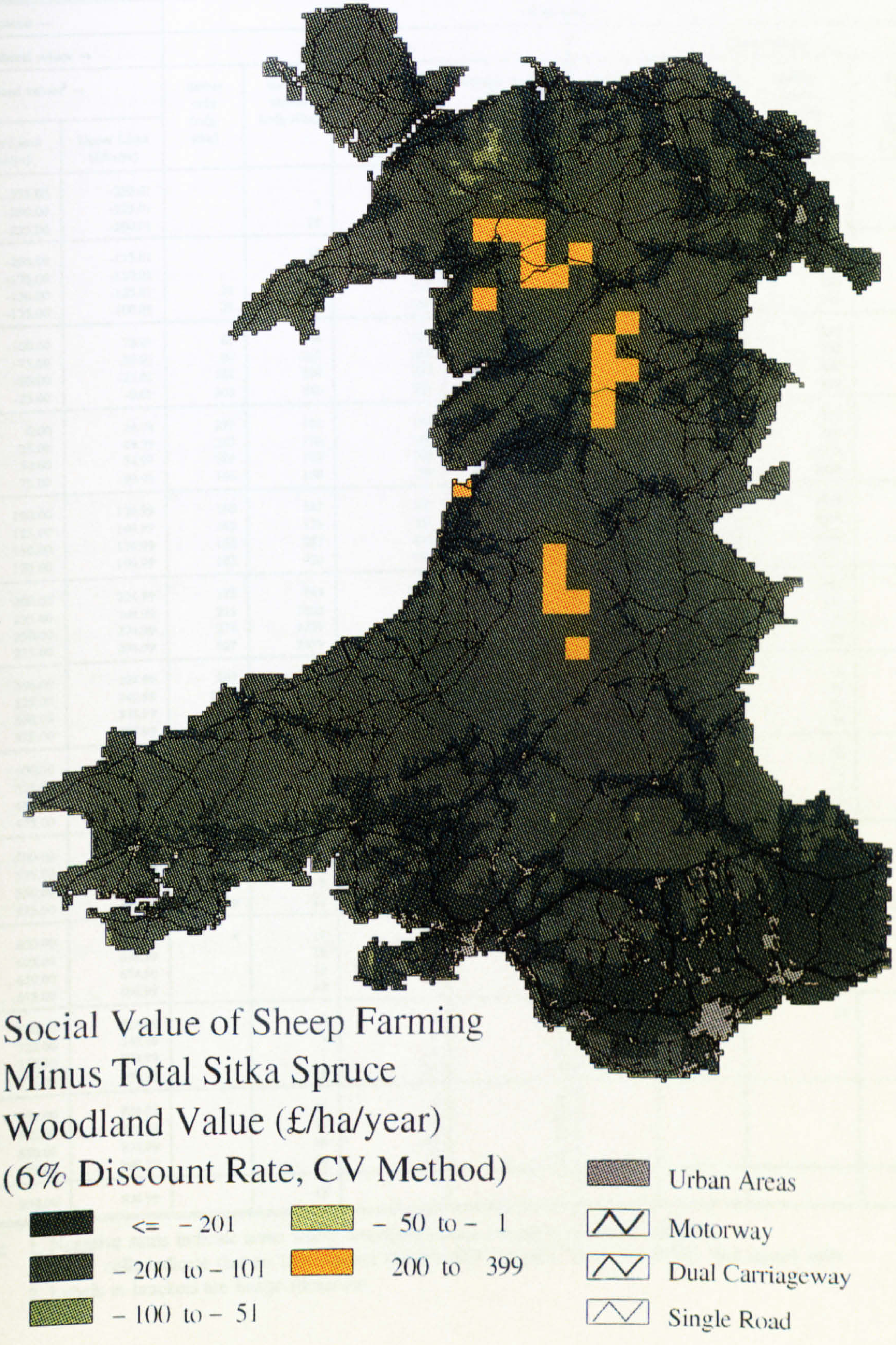


Table 10.2: Distribution of the net benefits of retaining dairy farming in Wales as opposed to conversion to conifer woodland[1]: 6% discount rate (£/ha/yr: 1990)

Tree species →		Sitka spruce							
Agricultural values →		Farm gate values				Social values			
Woodland values[2] →		timber only (mfg-s6a)	timber+ carbon (mfg-s6za)	timber+ carbon+ recreation (CVM) (mfg-s6zc)	timber+ carbon+ recreation (TCM) (mfg-s6zt)	timber only (mso-s6a)	timber+ carbon (mso-s6za)	timber+ carbon+ recreation (CVM) (mso-s6zc)	timber+ carbon+ recreation (TCM) (mso-s6zt)
Lower Limit (£/ha/yr)	Upper Limit (£/ha/yr)								
-275.00	-250.01				13				
-250.00	-225.01		3	24	39				
-225.00	-200.01		29	32	75				3
-200.00	-175.01		35	74	82			4	62
-175.00	-150.01		70	77	128		11	55	122
-150.00	-125.01	21	84	145	173		60	107	160
-125.00	-100.01	29	175	197	191		105	191	270
-100.00	-75.01	65	184	210	221	2	211	289	422
-75.00	-50.01	94	227	250	258	37	308	297	568
-50.00	-25.01	168	266	273	260	103	344	422	682
-25.00	-0.01	203	290	209	208	188	423	413	737
0.00	24.99	293	181	182	210	362	322	473	887
25.00	49.99	355	176	164	215	442	299	763	1180
50.00	74.99	389	136	149	224	543	377	1174	2114
75.00	99.99	166	150	150	351	339	1080	2324	3176
100.00	124.99	160	147	251	542	285	1775	3849	3826
125.00	149.99	163	173	351	530	302	4272	4658	3523
150.00	174.99	163	227	443	702	523	5446	3522	1693
175.00	199.99	143	420	765	1163	1401	3331	1031	388
200.00	224.99	175	743	1058	1700	2245	1234	316	151
225.00	249.99	215	1003	1649	2162	4969	351	131	72
250.00	274.99	277	1239	2389	2572	5138	86	33	28
275.00	299.99	527	2359	2978	2630	2636	29	20	10
300.00	324.99	847	3296	2976	2475	808	10	4	9
325.00	349.99	1089	3113	2589	1898	184	7	14	22
350.00	374.99	1578	2616	1676	796	41	19	30	48
375.00	399.99	2618	1734	639	252	15	38	54	86
400.00	424.99	3224	784	240	183		83	95	78
425.00	449.99	3025	321	149	55		100	79	37
450.00	474.99	2389	118	28	21		33	9	17
475.00	499.99	1380	30	28	27		15	24	26
500.00	524.99	559	27	20	20		25	22	16
525.00	549.99	140	20	15	11		14	22	16
550.00	574.99	75	9	13	12		25	19	21
575.00	599.99	29	11	8	15		17	8	4
600.00	624.99	4	12	18	12		2	4	33
625.00	649.99		16	9	9		35	56	26
650.00	674.99		15	21	14		26	10	19
675.00	699.99		10	0	0		23	29	31
700.00	724.99		0	3	3		27	12	
725.00	749.99		3	0	4				
750.00	774.99		1	9	37				
775.00	799.99		34	34	6				
800.00	824.99		11	4	14				
825.00	849.99		14	24	13				
850.00	874.99		19	23	25				
875.00	899.99		20	17	12				
900.00	924.99		12						

Notes: 1. Negative sums indicate areas where woodland values exceed agricultural values.
Blank cells indicate that no 1km squares fall into this category. There are 20563 1km square cells.
2. Labels in brackets are image filenames.

The overall pattern of values shown in table 10.2 is similar to that for sheep farms with expansions of the definition of woodland benefits increasing its value. However, the pattern of farm gate values illustrated in figure 10.3 (where woodland benefits are defined as purely timber related) is different to its sheep farm equivalent (figure 10.1). Here we find that the optimal locations for conversion to woodland (shown as negative sums) are clustered in upland rather than lowland areas. This difference in itself is of interest and seems to show that, whereas in the sheep sector analysis it was the superiority of woodland in the lowland areas which was the driving force behind the net benefit of conversions, here it is the fall off in milk farm values as we approach the most upland areas which allows woodland to become viable - but only at the extremes of topography. This difference is repeated in our social value analysis of the wider definition of woodland values (figure 10.4) where (with the exception of peat soil lands) it is again the upland which show more promise of conversion benefits (in contrast to the sheep farm equivalent illustrated in figure 10.2).

However, the most noticeable difference between our sheep and milk farm analyses is in the absolute level of conversion values concerned. Even when all possible woodland values are considered, milk values almost always substantially exceed those generated by woodlands. Given that we know there are very few milk farms in the extreme upland areas of Wales this result is probably even stronger than table 10.2 indicates. Furthermore as the discount rate used here is not out of line with (and may even be below) that likely to be used by milk farmers in everyday decision making any increase in the discount rate due to risk aversion would only reinforce this result. The social value assessment given here uses the Government discount rate and so results are valid as they stand. In summary conversions out of milk production and into woodland are generally not justified by this study.

We now broaden our analysis to consider changes in the species of tree used in conversions.

10.2.1.2: Conversion to broadleaf woodland.

Sheep farms

Table 10.3 details results for conversions from sheep farming to broadleaf woodland, maintaining the discount rate at 6%.

Figure 10.3: The farm gate net benefit of retaining dairy farming as opposed to conversion to conifer woodland (defined as timber plus grants only, i.e. present situation): 6% discount rate (£/ha/yr: 1990)

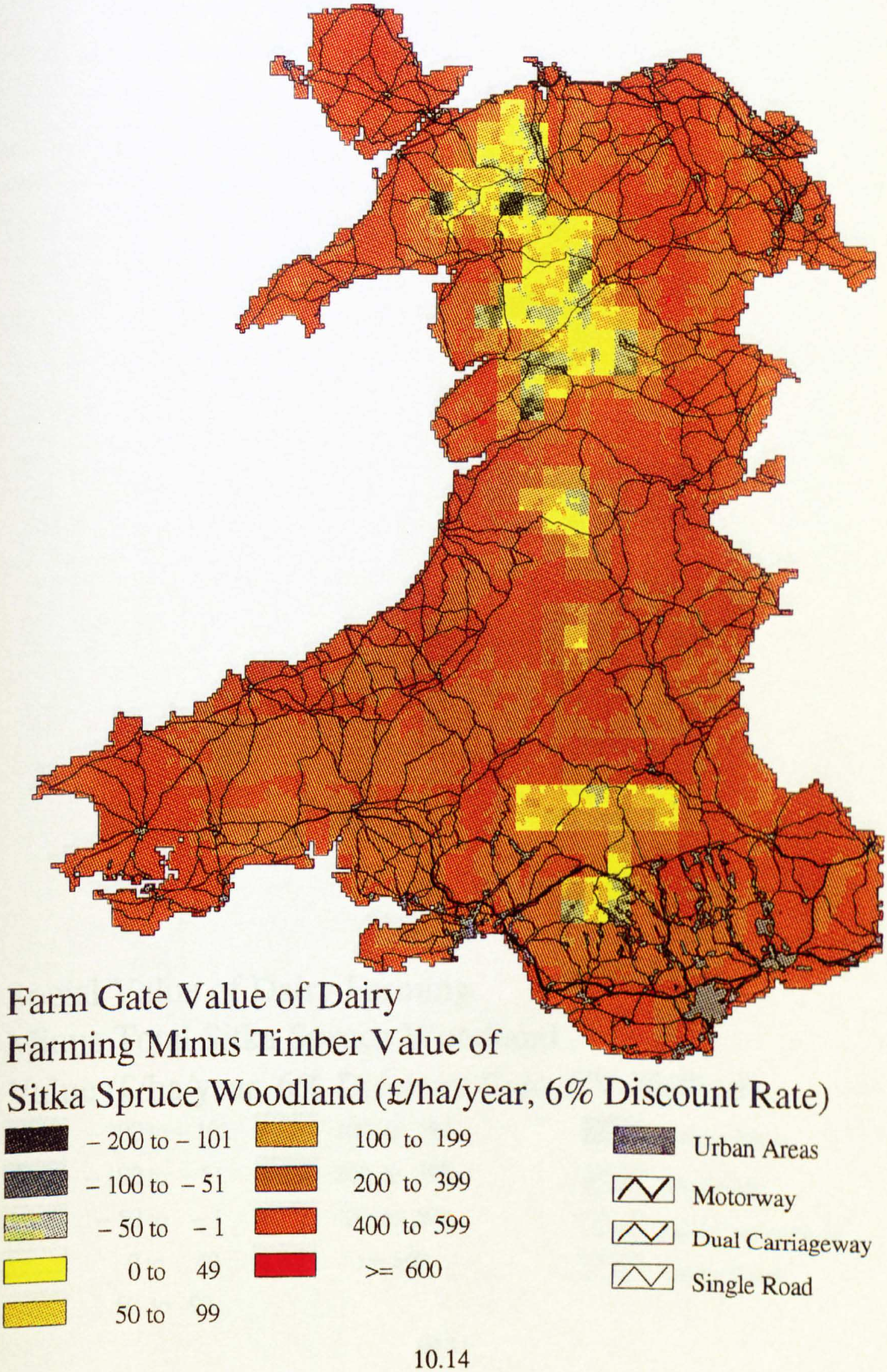


Figure 10.4: The social net benefit of retaining dairy farming as opposed to conversion to conifer woodland (defined as timber, carbon storage and recreation; the latter measured using contingent valuation): 6% discount rate (£/ha/yr: 1990)

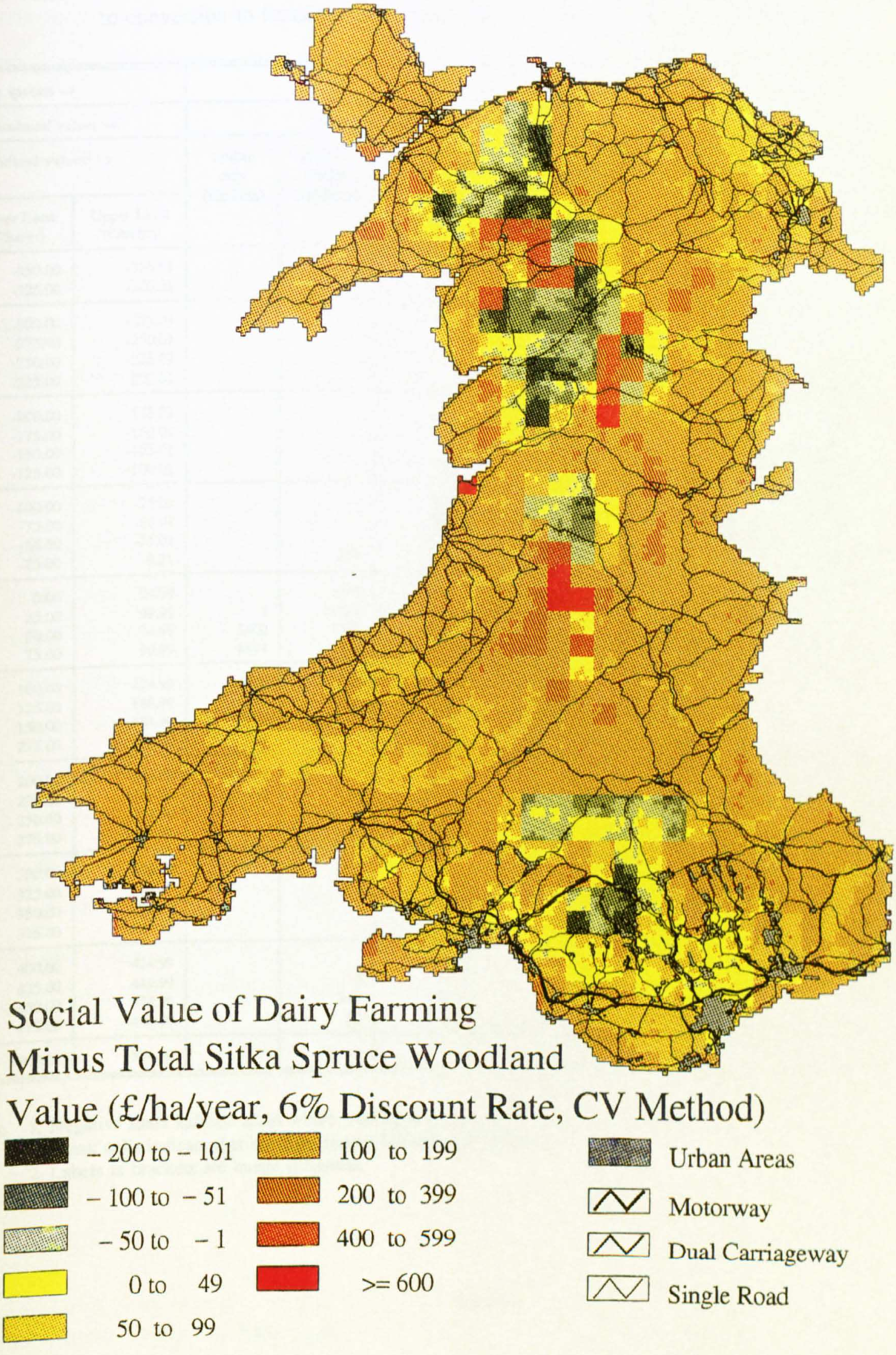


Table 10.3: Distribution of the net benefits of retaining sheep farming in Wales as opposed to conversion to broadleaf woodland[1]: 6% discount rate (£/ha/yr: 1990)

Tree species →		beech							
Agricultural values →		Farm gate values				Social values			
Woodland values[2] →		timber only (sfg-b6ta)	timber+ carbon (sfg-b6za)	timber+ carbon+ recreation (CVM) (sfg-b6zc)	timber+ carbon+ recreation (ITCM) (sfg-b6zi)	timber only (sso-b6ta)	timber+ carbon (sso-b6za)	timber+ carbon+ recreation (CVM) (sso-b6zc)	timber+ carbon+ recreation (ITCM) (sso-b6zi)
Lower Limit (£/ha/yr)	Upper Limit (£/ha/yr)								
-350.00	-325.01								25
-325.00	-300.01								54
-300.00	-275.01								151
-275.00	-250.01								174
-250.00	-225.01				25				312
-225.00	-200.01				114			14	431
-200.00	-175.01				126			177	923
-175.00	-150.01				193			434	1159
-150.00	-125.01				294			1259	3345
-125.00	-100.01			25	465		236	5089	7128
-100.00	-75.01			223	993		5775	8588	5160
-75.00	-50.01			469	1411		10289	3891	925
-50.00	-25.01			1517	3916	3166	3074	401	190
-25.00	-0.01		427	5676	7000	6669	464	140	94
0.00	24.99		6345	8991	4538	8822	232	81	3
25.00	49.99	1	10816	2500	608	1392	4		
50.00	74.99	3400	1703	294	172	317			
75.00	99.99	8894	295	211	125	197			
100.00	124.99	6810	269	74	17				
125.00	149.99	872	101	91	77				
150.00	174.99	173	118	3					
275.00	199.99	214							
200.00	224.99	159							
225.00	249.99	40							
250.00	274.99								
275.00	299.99								
300.00	324.99								34
325.00	349.99							165	380
350.00	374.99						418	305	65
375.00	399.99						57	19	10
400.00	424.99				51		14		
425.00	449.99		3	174	343				
450.00	474.99		393	282	88				
475.00	499.99		86	33	7				
500.00	524.99		7						

Notes: 1. Negative sums indicate areas where woodland values exceed agricultural values. Blank cells indicate that no 1km squares fall into this category.
2. Labels in brackets are image filenames.

In discussing table 10.3 it is useful to contrast these results with the sheep to conifer conversion detailed in table 10.1. In the latter, if we consider only timber values then while conversion generally (but not always) failed to generate net benefits when viewed from the farm gate, it did almost always create social gains. However, the case for conversion is less clear in the present analysis where the slow growth rates associated with broadleaf's mean that delayed timber benefits are heavily discounted such that in less than half of the cells is conversion justified upon social grounds and in no cases do farm gate values support conversion.

Broadening the definition of woodland benefits to include carbon sequestration does improve the farm gate case for conversion although in almost all cases the value of sheep farming marginally outperforms that of woodland. However, social values now generally support conversion except on peat soil areas.

Turning to consider recreation values we have up to this point focused attention upon the lower bound CV measures. However, while evidence of a link between tree species and recreation values is somewhat anecdotal[10], we feel that the use of upper bound measures has at least some justification here. The use of such measures does significantly improve the apparent viability of broadleaf woodland with virtually all cells producing net social benefits and most generating farm gate gains from conversion. However, the substitution effects upon recreation values discussed earlier mean that we cannot accept these results at face value. Clearly the large scale planting of woodland would very significantly reduce the marginal value of new areas. Rather we have to interpret table 10.3 as indicating the potential for at least some areas of conversion out of sheep and into broadleaf woodland. This being so it is of more interest to use this analysis to identify where those optimum conversion sites might be located. Figure 10.5 illustrates the farm gate value of conversion using our wider definition of woodland benefits (and the upper bound ITCM value of recreation), i.e. image sfg-b6zt, while figure 10.6 illustrates the social value equivalent of this analysis, i.e. image sso-b6zt.

[10]See our review of work by Hanley and Ruffell (1991, 1992) on this subject in appendix 1.

Figure 10.5: Farm gate net benefit value of retaining sheep farming as opposed to conversion to broadleaf woodland (defined as timber, carbon storage and recreation - the latter valued using the ITC measure): 6% discount rate (£/ha/yr: 1990)

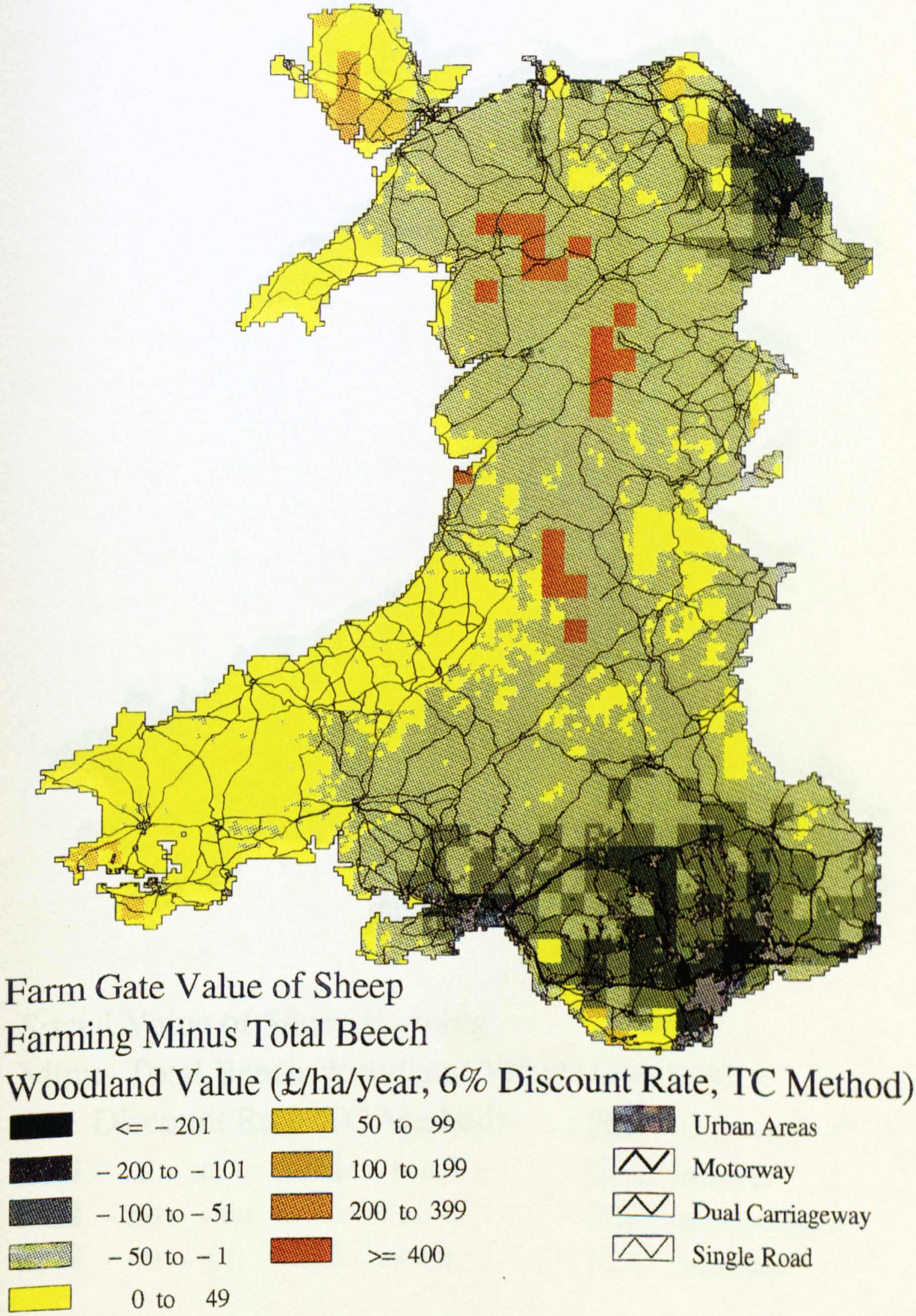
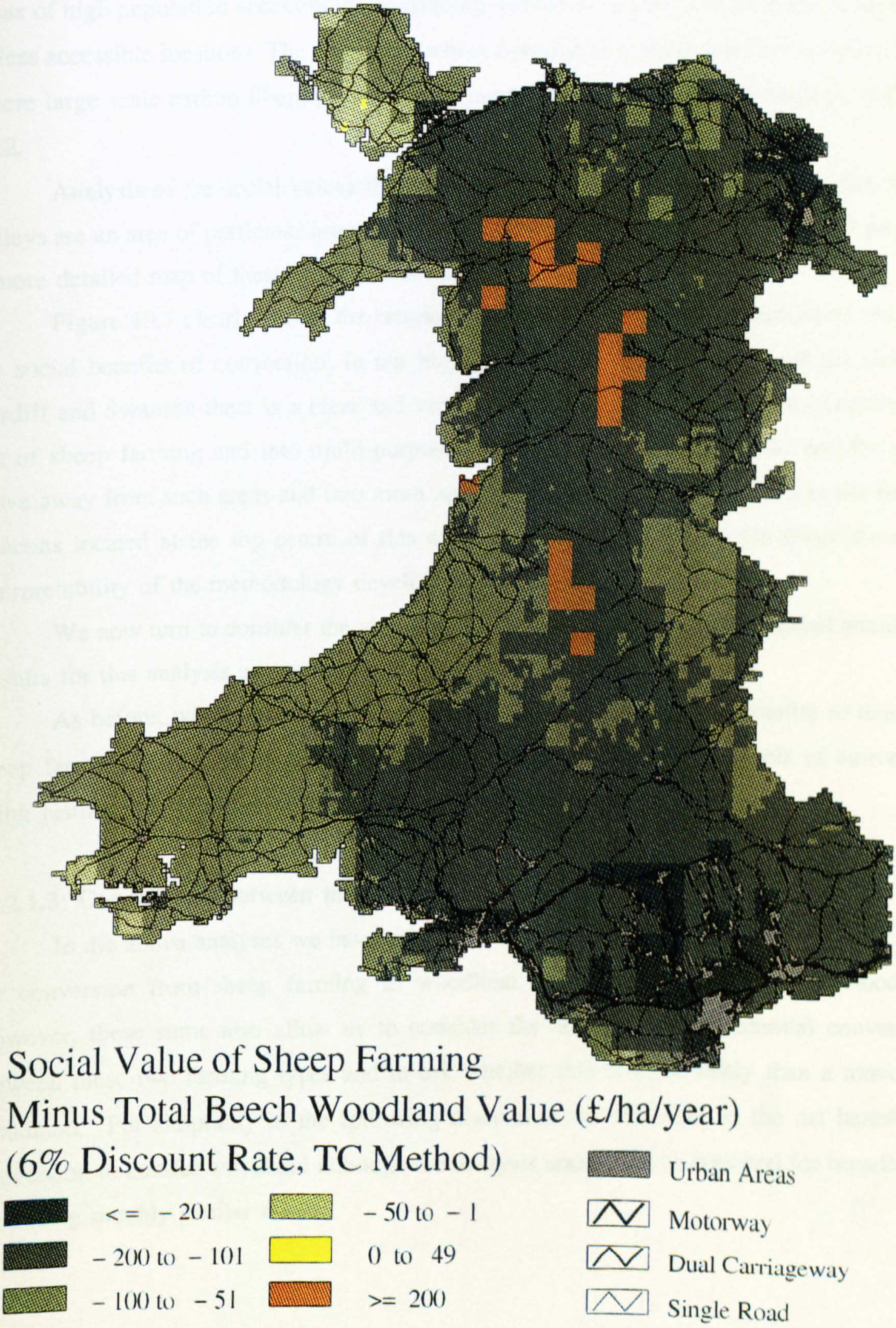


Figure 10.6: Social net benefit value of retaining sheep farming as opposed to conversion to broadleaf woodland (defined as timber, carbon storage and recreation - the latter valued using the ITC measure): 6% discount rate (£/ha/yr: 1990)



It is clear from both figure 10.5 and figure 10.6 that, when our wider woodland benefits definition is applied the net benefits of conversion from sheep rearing are highest in areas of high population accessibility (enhancing recreation values) and decrease as we move to less accessible locations. The only areas where conversion is never justified is on peat soils where large scale carbon liberation occurs. This echoes, in particular, the findings of figure 10.2.

Analysis of the social values illustrated in figure 10.6 indicates that the South Wales valleys are an area of particular interest and to facilitate closer inspection figure 10.7 presents a more detailed map of these values in this area.

Figure 10.7 clearly shows the relationship between population accessibility and high net social benefits of conversion. In the highly populated valleys and around the cities of Cardiff and Swansea there is a clear and very substantial net social benefit from conversion out of sheep farming and into multi-purpose broadleaf woodland. This falls rapidly as we move away from such areas and into more inaccessible and upland areas such as the Brecon Beacons located at the top centre of this map. The figure also amply illustrates the ready interpretability of the methodology developed in this research.*Milk farms*

We now turn to consider the viability of transfers from milk into broadleaf woodland. Results for this analysis are presented in table 10.4.

As before, while the pattern of results obtained for milk farms is similar to those for sheep farms, the absolute values are very different with insignificant levels of conversion being justified under either of the farm gate and social value analyses.

10.2.1.3: Conversions between milk and sheep farming

In the above analyses we have calculated both farm gate and social net benefit sums for conversion from sheep farming to woodland and from milk farming to woodland. However, these sums also allow us to consider the net benefits of potential conversions between these two farming types and to ask whether this is more likely than a move into woodland. For simplicity in the following discussion we will refer to the net benefits of conversion to conifer woodland although the analysis could also be repeated for broadleaves producing roughly similar results.

Figure 10.7: Social net benefit value of retaining sheep farming as opposed to conversion to broadleaf woodland (defined as timber, carbon storage and recreation - the latter valued using the ITC measure), detail of South Wales: 6% discount rate (£/ha/yr: 1990)

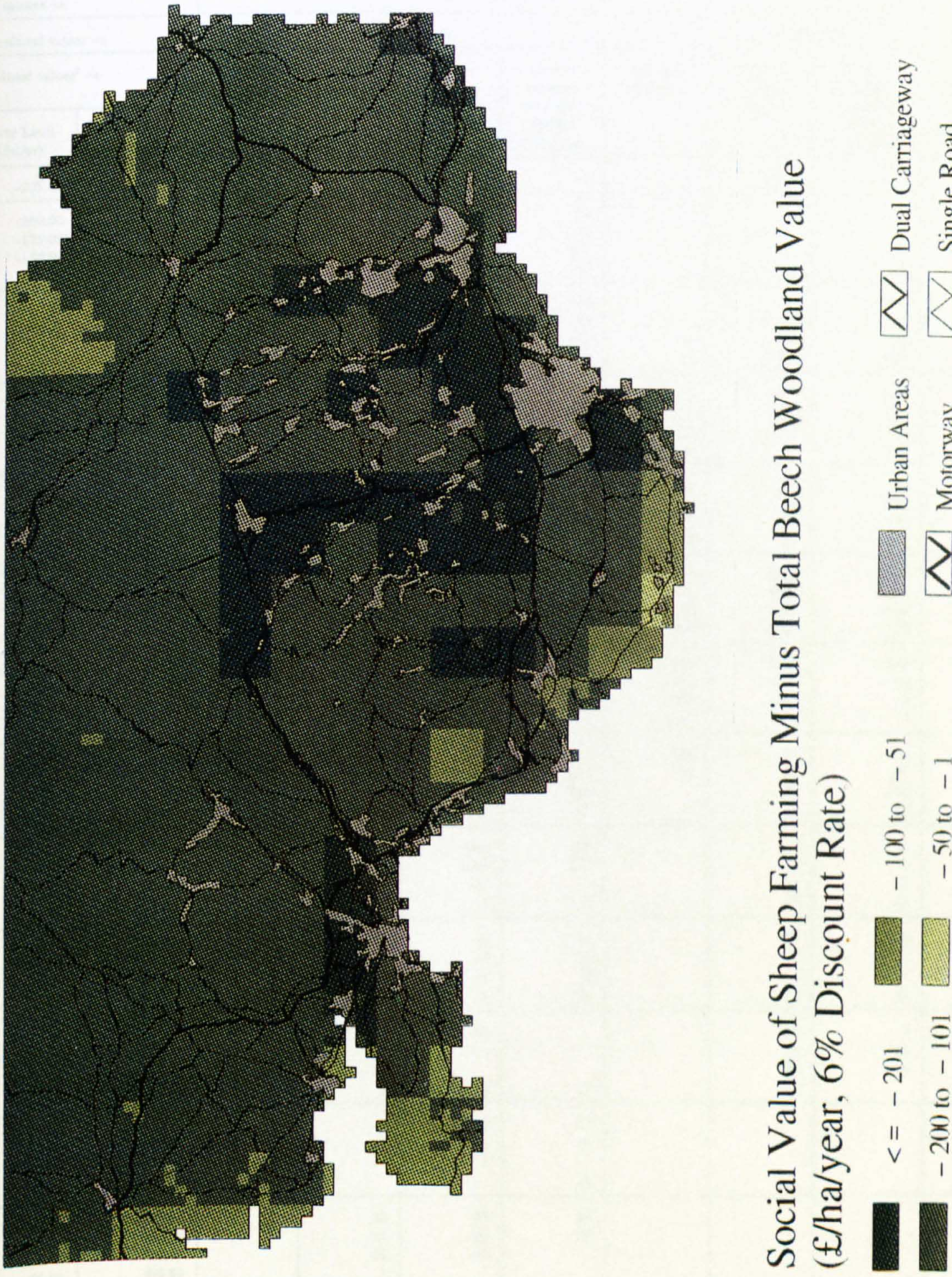


Table 10.4: Distribution of the net benefits of retaining dairy farming in Wales as opposed to conversion to broadleaf woodland[1]: 6% discount rate (£/ha/yr: 1990)

Tree species →		beech							
Agricultural values →		Farm gate values				Social values			
Woodland values[2] →		timber only (mfg-b6ta)	timber+ carbon (mfg-b6za)	timber+ carbon+ recreation (CVM) (mfg-b6zc)	timber+ carbon+ recreation (TTCM) (mfg-b6zt)	timber only (mso-b6ta)	timber+ carbon (mso-b6za)	timber+ carbon+ recreation (CVM) (mso-b6zc)	timber+ carbon+ recreation (TTCM) (mso-b6zt)
Lower Limit (£/ha/yr)	Upper Limit (£/ha/yr)								
-225.00	-200.01				16				
-200.00	-175.01		3	17	20				
-175.00	-150.01		17	15	26				
-150.00	-125.01		14	35	100				25
-125.00	-100.01	11	49	100	118			21	74
-100.00	-75.01	20	81	156	188		31	44	148
-75.00	-50.01	19	187	146	186		61	181	203
-50.00	-25.01	79	136	270	295	11	192	288	371
-25.00	-0.01	174	283	335	326	27	309	440	520
0.00	24.99	158	455	253	179	118	608	415	358
25.00	49.99	293	146	175	117	304	268	224	419
50.00	74.99	489	151	78	129	518	191	254	452
75.00	99.99	346	103	160	149	648	247	255	649
100.00	124.99	154	130	148	178	216	233	418	769
125.00	149.99	100	153	133	203	233	250	628	923
150.00	174.99	148	142	138	249	255	376	889	1675
175.00	199.99	140	125	156	364	230	838	1987	2995
200.00	224.99	150	140	289	404	340	1638	3120	3558
225.00	249.99	157	203	296	458	465	2934	4164	3341
250.00	274.99	128	237	385	601	1283	4699	3956	2465
275.00	299.99	183	329	702	1274	1910	4236	2349	959
300.00	324.99	255	758	1079	1402	3843	2386	342	152
325.00	349.99	239	964	1350	2026	4449	473	96	17
350.00	374.99	446	1172	2142	2353	3908	103	3	1
375.00	399.99	931	1947	2492	2472	1471	1	4	25
400.00	424.99	1011	2671	2800	2238	297	18	33	49
425.00	449.99	1483	2903	2583	2250	37	32	96	119
450.00	474.99	2286	2708	2157	1234		131	128	83
475.00	499.99	2740	2213	1257	583		95	18	6
500.00	524.99	2564	1231	344	121		7	21	18
525.00	549.99	2568	424	144	104		17	3	13
550.00	574.99	1807	216	35	9		11	22	34
575.00	599.99	1003	80	4	7		25	26	7
600.00	624.99	328	8	11	13		38	24	21
625.00	649.99	116	9	14	24		1		
650.00	674.99	36	21	20	9		2	4	31
675.00	699.99	1	16	8	24		24	41	19
700.00	724.99		24	22			24	5	8
725.00	749.99						25	38	56
750.00	774.99						38	26	
775.00	799.99		2	2	4		1		
800.00	824.99		2	24	28				
825.00	849.99		25	18	18				
850.00	874.99		21	6					
875.00	899.99				10				
900.00	924.99		25	25	28				
925.00	949.99		13	25	26				
950.00	974.99		25	14					
975.00	999.99		1						

Notes: 1. Negative sums indicate areas where woodland values exceed agricultural values. Blank cells indicate that no 1km squares fall into this category.
2. Labels in brackets are image filenames.

Considering present day farm gate values (i.e. ignoring non-timber woodland benefits) then we have shown that in lowland areas sheep generally but only marginally outperforms woodland with some conversions being viable where poorer soils predominate (for example the north west area of Wales as illustrated in figure 10.1). However, the farm gate value of dairying (figure 10.3) always and very substantially outperforms that of woodland in such lowland areas and consequently exceeds the value of sheep farming by a similar extent. Moving to consider upland areas the farm gate value of sheep farming always exceeds that of woodland, this excess being in places over £100/ha. The picture for milk to woodland conversions in upland areas is more mixed. While in less extreme areas milk values still exceed those of woodland by over £200/ha, in the highest areas the situation changes rapidly as dairy values fall dramatically such that the net benefits of retaining milk production fall below £100/ha and in the most mountainous areas conversion to woodland becomes profitable. Therefore we can see that our model predicts that the farm gate value of sheep farming exceeds both that of woodland and milk production in these extreme areas. Such a prediction is borne out by actual behaviour as there are altitudes in Wales (see chapter 9 and appendix 7).

Turning to consider social values it is perhaps most valid to define woodland value using the full range of benefits considered in this study. Using this measure we can see that woodland substantially outperforms sheep farming (figure 10.2) but is itself consistently outperformed by dairying (figure 10.4) in lowland areas. Therefore, in a scenario of full agricultural liberalisation and farmers being paid for positive externalities we would expect no conversions from dairying but complete conversion from sheep farming primarily into milk (if all policy restrictions had been lifted) with woodland as a possible second choice[11]. However, such a result ignores the impacts upon milk price of such a supply expansion and given the very strong likelihood of entry restrictions remaining upon the milk market we believe that this does not invalidate analysis of the social value of potential conversions out of sheep farming and into woodland in lowland areas.

[11] As noted in chapter 1, this is only a partial CBA, we were not able to consider all possible opportunity costs - a characteristic failing of almost all practical CBA applications.

In the uplands the social value of woodland exceeds that of sheep farming in all but peat soil areas, with net benefits of conversion generally in the range of £100 to £200 per hectare. For dairy farming the picture is again less distinct with about the same area converting as not. In the former, the net benefits of conversion generally range up to about £100/ha with only a few areas exceeding this. Consequently we would expect all sheep farms to convert with roughly similar numbers turning to woodland as to milk farming, assuming no entry barriers. Given the improbable nature of the latter assumption we do not foresee movement from sheep to milk farming implying that all conversion will be towards woodland. The one exception throughout is the peat lands where afforestation is never justified on social grounds.

10.2.1.4: Results for the 6% discount rate: Summary

Looking back across the full range of analyses conducted using the 6% discount rate we can see that an economic case can be made for such conversions from sheep farming, particularly of lowland areas with high population accessibility, but that under present subsidy availability such conversion is not financially attractive to the farmer. Considering the choice of species, conifer woodlands generally seem to be a more viable option for conversion than broadleaves. However, in the following chapter we discuss omissions from this analysis (e.g. acidification impacts, biodiversity effect, etc.) which are generally favourable to broadleaf trees and mitigate against certain coniferous species. Given this it is interesting to note that our analysis of broadleaf values indicates that using the wider definition of benefits usually generates net benefits from sheep farming conversions.

Our analysis of milk farms suggests that in general there is not a strong economic case for conversions from this sector to either conifer or broadleaf woodland. One further interesting difference here was the result that if any such conversions to be justified these would be in upland (but non-peat) areas. This seems mainly attributable to a rapid fall off in milk values as we reach the upland extremes of the Welsh environment.

Having analysed the effects of changing tree species we now consider the effect of changing discount rates. Given our discussions of chapter 6 and above, any increase in rates seems unrealistic (and will almost inevitably rule out any feasibility of conversions), so a reduction seems more interesting.

10.2.2: RESULTS FOR THE 3% DISCOUNT RATE

A 3% discount rate is interesting for two reasons; firstly it more closely approximates what we believe to be the rate used by sheep farmers for everyday decision making; secondly it is closer to the social sustainability rates discussed by many commentators and reviewed in chapter 6. The 3% rate thus has applicability to the sheep farm gate results and to both the sheep and milk farm social value analyses.

10.2.2.1: Conversion to conifer woodland

Sheep farms

Table 10.5 reports results from the analysis of conversions from sheep to conifer using a 3% discount rate.

Considering the first column of the farm gate values block (image sfg-s3ta) of table 10.5 we can see that lowering the discount rate to 3% makes conversion from sheep into woodland beneficial for almost all farmers even when we only consider timber values and the present availability of grants and subsidies; figure 10.8 illustrates this image. Given that this scenario represents the present available return to farmers, why does such a rate of conversion not occur? The answer, as before, is most likely to be related to a risk premium. While this can be modelled as a higher required discount rate (as per section 10.2.1), it can also be assessed at existing typical discount rates as a requirement that unfamiliar conversion goods provide a substantially higher income than present output (our discussion of table 10.2 is relevant here).

As before, net savings on subsidies mean that social values of conversion under this scenario (image sso-s3ta) are substantially above farm gate values, indeed using this analysis, all Welsh sheep farms should be converted to woodland. Given that we are here ignoring all non-timber benefits this is a powerful result.

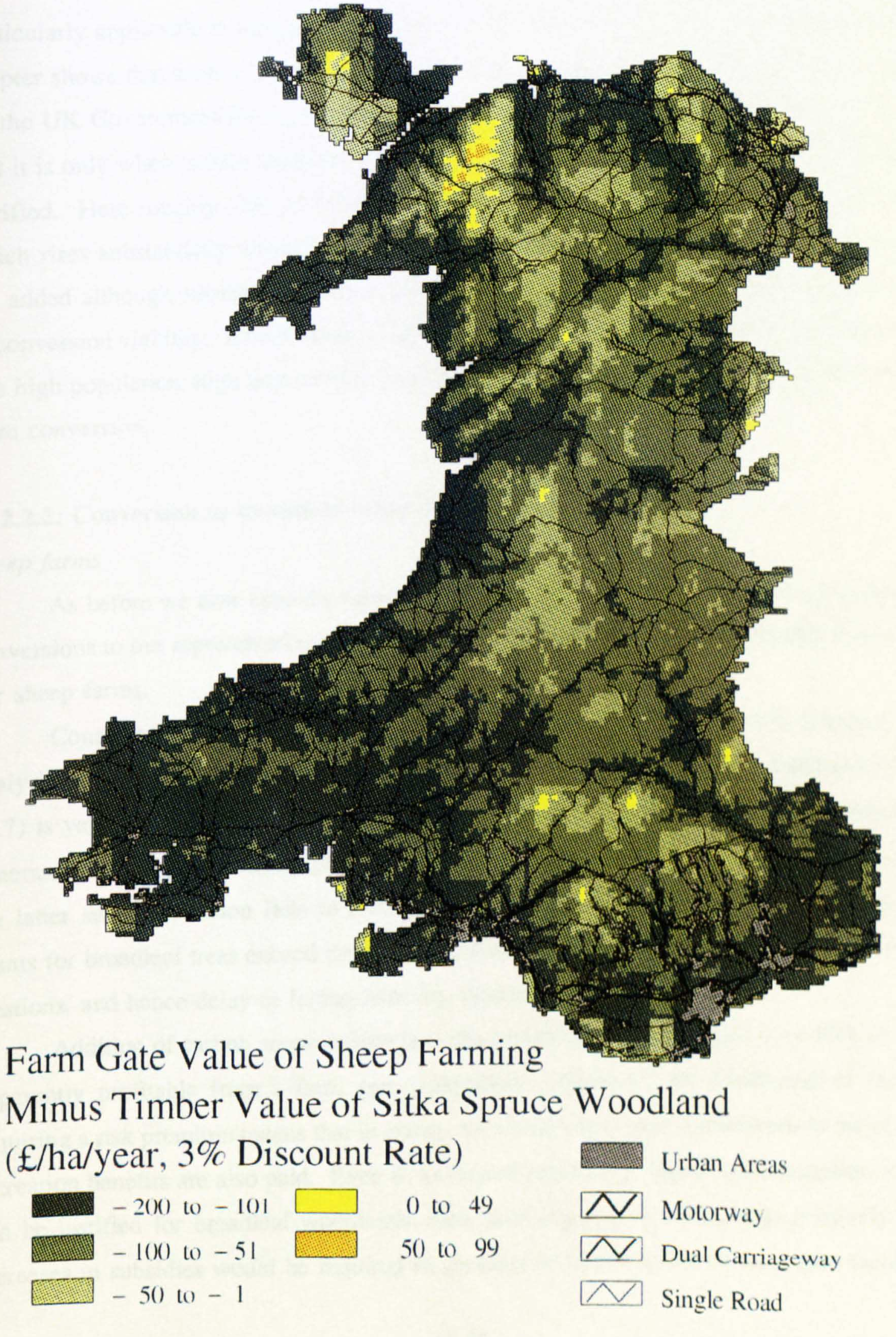
For both farm gate and social value analyses (image sfg-s3za and sso-s3za respectively) the addition of carbon sequestration values again produces a bimodal distribution with the majority of cells now more strongly benefiting from conversion to woodland. The further addition of recreation values reinforces this result.

Table 10.5: Distribution of the net benefits of retaining sheep farming in Wales as opposed to conversion to conifer woodland[1]: 3% discount rate (£/ha/yr: 1990)

Tree species →		Sitka spruce							
Agricultural values →		Farm gate values				Social values			
Woodland values[2] →		timber only (sfg-s3ta)	timber+ carbon (sfg-s3za)	timber+ carbon+ recreation (CVM) (sfg-s3zc)	timber+ carbon+ recreation (ITCM) (sfg-s3zt)	timber only (sso-s3ta)	timber+ carbon (sso-s3za)	timber+ carbon+ recreation (CVM) (sso-s3zc)	timber+ carbon+ recreation (ITCM) (sso-s3zt)
Lower Limit (£/ha/yr)	Upper Limit (£/ha/yr)								
-575.00	-550.01								29
-550.00	-525.01								128
-525.00	-500.01								73
-500.00	-475.01				9				199
-475.00	-450.01				37				217
-450.00	-425.01				125			61	378
-425.00	-400.01				116			155	803
-400.00	-375.01				169			321	1170
-375.00	-350.01				234			992	1823
-350.00	-325.01			93	478		37	2725	4216
-325.00	-300.01			200	912		2963	5814	5056
-300.00	-275.01			359	1233		6962	4959	2954
-275.00	-250.01			1263	2170	3	5092	2653	1612
-250.00	-225.01		246	3435	4326	839	2865	1475	934
-225.00	-200.01		3998	5464	4565	7486	1518	601	288
-200.00	-175.01		6549	5304	2721	6505	412	217	126
-175.00	-150.01	18	4452	2455	1532	3570	156	58	37
-150.00	-125.01	2024	2568	1487	907	1689	36	21	21
-125.00	-100.01	7549	1499	676	361	352	17	15	8
-100.00	-75.01	5610	554	238	113	82	13	6	2
-75.00	-50.01	3032	141	60	36	20	2	1	0
-50.00	-25.01	1671	34	18	20	14	1	0	16
-25.00	-0.01	526	16	15	8	3	14	18	10
0.00	24.99	98	14	6	1		7	26	70
25.00	49.99	17	2	1	4		51	109	143
50.00	74.99	15	1	10	13		169	199	194
75.00	99.99	3	16	8	10		207	122	51
100.00	124.99		5	29	74		36	13	5
125.00	149.99		53	106	146		5	2	
150.00	174.99		167	196	181				
175.00	199.99		194	124	56				
200.00	224.99		48	13	6				
225.00	249.99		6	3					
250.00	274.99								
275.00	299.99								
300.00	324.99								

Notes: 1. Negative sums indicate areas where woodland values exceed agricultural values.
Blank cells indicate that no 1km squares fall into this category. There are 20563 1km square cells.
2. Labels in brackets are image filenames.

Figure 10.8: Net farm gate benefit of retaining sheep farming as opposed to conversion to conifer woodland (defined as timber plus grants only, i.e. present situation): 3% discount rate (£/ha/yr: 1990).



Milk farms

Table 10.6 repeats the above analysis but now considers conversion from milk farms.

Following the discussion of chapter 6, the 3% discount rate is not seen as being particularly applicable to farm gate analyses of milk farm conversions. However, that same chapter shows that such a rate is, arguably, relevant to social values (although it is not used by the UK Government for such purposes). Examining the social values block we can see that it is only when carbon sequestration values are added in that significant conversions are justified. Here roughly 18% of cells generate net social benefits from conversion, a figure which rises substantially when lower bound (most appropriate) CV-based recreation values are added although substitution effects mean that this has to be a significant overstatement of conversion viability. Examination of the images underpinning these results confirmed that it is high population, high accessibility lowland areas which generate the highest net benefits from conversion.

10.2.2.2: Conversion to broadleaf woodland

Sheep farms

As before we now hold the discount rate constant (at 3%) and consider the impact of conversions to our representative broadleaf tree species: beech. Table 10.7 details results for our sheep farms.

Considering first the farm gate values, the contrast between our 3% discount rate analysis of conversions from sheep to conifers (table 10.5) as opposed to broadleaves (table 10.7) is very marked. Whereas present timber values and related grants were sufficient to generate net farm gate benefits from conversion in the former instances (image sfg-s3ta), for the latter such conversion fails to pass the cost-benefit test (image sfg-b3ta). Given that grants for broadleaf trees exceed those for conifers, this result seems to be due to the longer rotations, and hence delay to felling benefits, typical of broadleaves.

Addition of carbon sequestration benefits makes conversion of just over 10% of cells apparently profitable from a farm gate perspective. However, the likelihood of farmers requiring a risk premium means that in reality we would not expect conversions to occur until recreation benefits are also paid. Even if, as argued previously, higher rate recreation values can be justified for broadleaf woodlands, then such a premium means that relatively high increases in subsidies would be required to generate attractive levels of farm gate income.

Table 10.6: Distribution of the net benefits of retaining dairy farming in Wales as opposed to conversion to conifer woodland[1]: 3% discount rate (£/ha/yr: 1990)

Tree species →		Sitka spruce							
Agricultural values →		Farm gate values				Social values			
Woodland values[2] →		timber only (mfg-s3ta)	timber+ carbon (mfg-s3za)	timber+ carbon+ recreation (CVM) (mfg-s3zc)	timber+ carbon+ recreation (ITCM) (mfg-s3zt)	timber only (mso-s3ta)	timber+ carbon (mso-s3za)	timber+ carbon+ recreation (CVM) (mso-s3zc)	timber+ carbon+ recreation (ITCM) (mso-s3zt)
Lower Limit (£/ha/yr)	Upper Limit (£/ha/yr)								
-375.00	-350.01				4				
-350.00	-325.01		2	10	38				
-325.00	-300.01		14	37	52				5
-300.00	-275.01		36	50	68		2	12	33
-275.00	-250.01	2	55	68	95		15	23	117
-250.00	-225.01	17	70	91	144		27	83	118
-225.00	-200.01	34	96	176	180		83	134	236
-200.00	-175.01	63	193	192	178	10	142	218	452
-175.00	-150.01	78	185	188	197	36	243	285	464
-150.00	-125.01	132	204	206	230	90	285	286	722
-125.00	-100.01	209	226	258	296	165	325	475	890
-100.00	-75.01	234	278	252	253	311	395	614	1085
-75.00	-50.01	303	219	182	255	357	398	1003	1393
-50.00	-25.01	324	180	179	274	451	513	1592	2423
-25.00	-0.01	309	164	175	427	450	1330	2975	3503
0.00	24.999	191	154	260	527	358	2934	4134	3924
25.00	49.999	180	198	408	608	481	4981	4419	2846
50.00	74.99	165	252	498	853	1129	4462	2250	1029
75.00	99.99	159	502	937	1388	2023	2350	905	426
100.00	124.99	191	881	1261	1862	4699	932	385	271
125.00	149.99	245	1031	1835	2445	5083	447	241	182
150.00	174.99	416	1677	2803	2572	3050	246	165	136
175.00	199.99	788	2922	3104	2851	1167	139	109	78
200.00	224.99	1030	3386	3071	2253	435	85	45	31
225.00	249.99	1276	3123	2098	1389	189	29	28	27
250.00	274.99	2548	2164	1218	471	57	26	18	21
275.00	299.99	3220	1156	450	243	15	19	23	15
300.00	324.99	3316	616	198	126	7	19	14	19
325.00	349.99	2440	246	107	72		24	29	23
350.00	374.99	1501	104	58	40		16	10	16
375.00	399.99	746	51	29	24		19	22	28
400.00	424.99	254	32	34	31		26	26	19
425.00	449.99	125	29	15	4		22	25	22
450.00	474.99	31	6	4	2		20	15	9
475.00	499.99	22	0	0	4		9		
500.00	524.99	13	3	10	22				
525.00	549.99	1	34	45	35				
550.00	574.99		23	6	0				
575.00	599.99		2	10	13				
600.00	624.99		15	20	25				
625.00	649.99		22	11	12				
650.00	674.99		12	9					
675.00	699.99								
700.00	724.99								
725.00	749.99								
750.00	774.99								
775.00	799.99								

Notes: 1. Negative sums indicate areas where woodland values exceed agricultural values.
Blank cells indicate that no 1km squares fall into this category. There are 20563 1km square cells.
2. Labels in brackets are image filenames.

Table 10.7: Distribution of the net benefits of retaining sheep farming in Wales as opposed to conversion to broadleaf woodland[1]: 3% discount rate (£/ha/yr: 1990)

Tree species →		Beech							
Agricultural values →		Farm gate values				Social values			
Woodland values[2] →		timber only (sfg-b3ta)	timber+ carbon (sfg-b3za)	timber+ carbon+ recreation (CVM) (sfg-b3zc)	timber+ carbon+ recreation (ITCM) (sfg-b3zt)	timber only (sso-b3ta)	timber+ carbon (sso-b3za)	timber+ carbon+ recreation (CVM) (sso-b3zc)	timber+ carbon+ recreation (ITCM) (sso-b3zt)
Lower Limit (£/ha/yr)	Upper Limit (£/ha/yr)								
-575.00	-550.01								
-550.00	-525.01								
-525.00	-500.01								
-500.00	-475.01								
-475.00	-450.01								
-450.00	-425.01								
-425.00	-400.01								
-400.00	-375.01								
-375.00	-350.01								25
-350.00	-325.01								14
-325.00	-300.01								178
-300.00	-275.01								102
-275.00	-250.01				25				308
-250.00	-225.01				61			1	364
-225.00	-200.01				158			102	709
-200.00	-175.01				141			334	1047
-175.00	-150.01				260			740	1962
-150.00	-125.01			19	397		24	2826	5691
-125.00	-100.01			165	795		2492	7718	7189
-100.00	-75.01			350	1222		9828	7432	2089
-75.00	-50.01			897	2181	362	6691	619	287
-50.00	-25.01		42	3284	6196	6512	740	205	92
-25.00	-0.01		2967	8853	6668	10498	231	97	17
0.00	24.99		11859	5629	1533	2565	68	0	0
25.00	49.99	567	4288	462	182	405	0	0	0
50.00	74.99	7413	398	175	156	220	0	0	0
75.00	99.99	10549	259	140	11	1	0	0	0
100.00	124.99	1336	92	81	88		0	0	0
125.00	149.99	231	169	19	0		0	0	68
150.00	174.99	257	0	0	0		12	194	331
175.00	199.99	135	0	0	0		395	279	90
200.00	224.99	75	0	0	0		82	16	
225.00	249.99		0	1	71				
250.00	274.99		16	198	319				
275.00	299.99		378	270	97				
300.00	324.99		95	20	2				

Notes: 1. Negative sums indicate areas where woodland values exceed agricultural values.
Blank cells indicate that no 1km squares fall into this category. There are 20563 1km square cells.
2. Labels in brackets are image filenames.

Turning to consider social values, and remembering that sustainability criteria may justify use of the 3% rate here, we can see that even if we only consider timber benefits a large majority (84%) of cells would pass a cost-benefit test of conversion. Addition of carbon benefits indicates that almost the only cells that would not pass such a test are those located on peat soils. Further addition of recreation benefits merely reinforces this result.

Milk farms

Table 10.8 details results for a conversion from milk farming to broadleaf woodland under a 3% discount rate.

Consideration of the farm gate values detailed in table 10.8 has to be tempered by the knowledge that a 3% rate is lower than that we would expect milk farmers to use for everyday decision making (and that a risk weighted rate would be even higher than this). Even so, table 10.8 indicates that the long delays associated with broadleaves mean that farm gate values do not justify anything but the most minor conversions even when all benefits are paid. The situation with social values is very similar with little conversion out of milk justified.

10.2.3: OTHER DISCOUNT RATES

Given the above discussions and comparisons with observed rates of conversion, it seems likely that farmers are attaching significant risk premiums to any decision to convert to woodland, an observation made elsewhere regarding other non-standard production (Cobb, 1993). This can either be modelled as a required surplus of net benefits or as an inflated discount rate. Given this consideration of further reductions in discount rate (to the 1 % rate or the roughly equivalent 6% hyperbolic rate used elsewhere in this study) does not appear to be justified[12].

[12]Analysis of lower and hyperbolic discount rate scenarios was undertaken. These merely extend the trends observed when we moved from a 6% to a 3% discount rate.

Table 10.8: Distribution of the net benefits of retaining dairy farming in Wales as opposed to conversion to broadleaf woodland[1]: 3% discount rate (£/ha/yr: 1990)

Tree species →		beech							
Agricultural values →		Farm gate values				Social values			
Woodland values[2] →		timber only (mfg-b3ta)	timber+ carbon (mfg-b3za)	timber+ carbon+ recreation (CVM) (mfg-b3zc)	timber+ carbon+ recreation (ITCM) (mfg-b3zt)	timber only (mso-b3ta)	timber+ carbon (mso-b3za)	timber+ carbon+ recreation (CVM) (mso-b3zc)	timber+ carbon+ recreation (ITCM) (mso-b3zt)
Lower Limit (£/ha/yr)	Upper Limit (£/ha/yr)								
-375.00	-350.01								
-350.00	-325.01								
-325.00	-300.01								
-300.00	-275.01								
-275.00	-250.01								
-250.00	-225.01				8				
-225.00	-200.01			11	15				
-200.00	-175.01		11	18	21				
-175.00	-150.01		20	18	61				9
-150.00	-125.01	3	22	63	114			11	44
-125.00	-100.01	20	69	113	136		14	27	106
-100.00	-75.01	11	124	147	179		32	106	158
-75.00	-50.01	55	156	192	217	3	111	203	278
-50.00	-25.01	91	214	266	306	28	235	344	413
-25.00	-0.01	204	273	379	266	64	371	433	460
0.00	24.99	174	395	175	174	216	528	359	471
25.00	49.99	345	143	155	130	362	238	231	436
50.00	74.99	543	118	92	159	710	255	258	488
75.00	99.99	202	121	191	144	357	228	343	809
100.00	124.99	151	159	128	205	213	230	552	822
125.00	149.99	113	146	126	201	253	309	754	1375
150.00	174.99	153	129	150	349	248	566	1457	2428
175.00	199.99	145	148	259	412	292	1396	2619	3388
200.00	224.99	142	205	320	532	401	2128	4117	3564
225.00	249.99	145	236	360	561	926	4374	4160	3295
250.00	274.99	161	325	643	959	1649	4986	3258	1436
275.00	299.99	209	687	981	1506	3204	3272	954	322
300.00	324.99	270	962	1262	1789	4722	916	130	44
325.00	349.99	355	1014	1843	2212	4259	156	56	28
350.00	374.99	796	1601	2392	2546	2189	29	8	20
375.00	399.99	949	2495	2847	2267	377	13	20	27
400.00	424.99	1214	2947	2521	2360	89	26	25	9
425.00	449.99	2031	2786	2455	1520	1	25	24	19
450.00	474.99	2686	2310	1576	817		11	0	3
475.00	499.99	2836	1680	543	150		2	4	40
500.00	524.99	2710	614	117	95		27	43	7
525.00	549.99	2055	209	91	35		21	3	10
550.00	574.99	1155	117	13	3		20	52	54
575.00	599.99	399	12	2	1		44	12	
600.00	624.99	175	3	3	3				
625.00	649.99	62	2	24	36				
650.00	674.99	3	26	18	10				
675.00	699.99		20	5	0				
700.00	724.99		0	1	11				
725.00	749.99		20	30	27				
750.00	774.99		18	33	26				
775.00	799.99		26						

Notes: 1. Negative sums indicate areas where woodland values exceed agricultural values.
Blank cells indicate that no 1km squares fall into this category. There are 20563 1km square cells.
2. Labels in brackets are image filenames.

10.3 : CONCLUSIONS

On inspection of the analyses presented in this chapter we feel that the link between our value estimates calculated at a 6% discount rate, the theoretical case for using such a rate, and the rates of conversion observed in reality, is compelling. Furthermore, the fact that this is also the UK Governments chosen discount rate for socially beneficial project makes the analyses reported in tables 10.1 to 10.4 of particular interest.

Considering conifer woodlands first, table 10.1 indicated that for sheep farmers the present level of grants and subsidies is insufficient to justify conversion. However, increasing these transfers in line with the wider definition external woodland benefits would substantially shift the balance of farm gate values in favour of conversion. Furthermore, our analysis suggests that relatively modest increases in woodland subsidy could result in significant rates of uptake amongst Welsh sheep farmers. Interestingly our analysis of social values shows that these are already strongly in favour of conversion and that the increase in subsidies outlined above could generate very substantial net social benefits. However, turning to consider milk farms, table 10.2 suggests that neither farm gate not social values justify substantial transfers out of this sector and into conifer woodlands.

When we consider conversions to broadleaf woodlands, table 10.3 indicates that the long rotation periods implied by a 6% discount rate mitigate against timber values and limit the scope for conversions from sheep farms when assessed in terms of resultant farm gate income. However, broadening the definition of benefits had a substantial impact here, generally changing the farm gate result in favour of conversion. Similarly social values, which were more favourable than their farm gate equivalents, became strongly supportive of conversion where the wider benefits definition was employed. However, table 10.4 shows that under a 6% discount rate, our analysis suggests that conversion from milk farming to broadleaf woodland are not generally justified.

Shifting to a 3% discount rate considerably increased the benefits of woodland and so strengthens the case for conversion from sheep farming. However, while such a rate may theoretically be justified for the calculation of social net benefits, it is not in line with present government policy and does not seem to reflect sheep farmers attitudes towards this type of conversion. Furthermore, this switch does not fundamentally alter the position with regard to farm gate values on milk farms, some positive net social benefits may be derived from conversion if a wide definition of woodland benefits is employed. Such a low discount rate is probably not valid for assessment of farm gate values on milk farms.

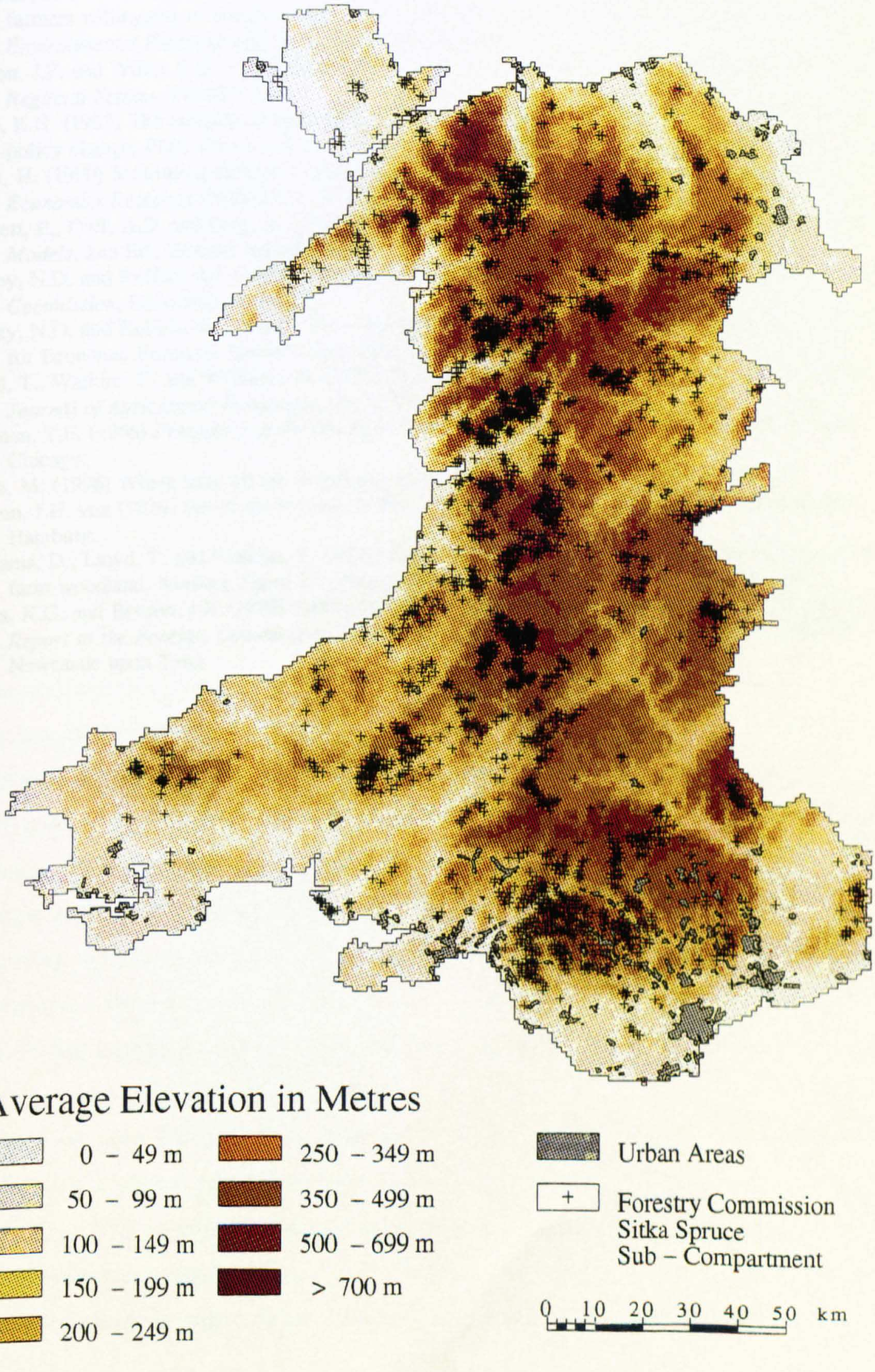
Clearly if conversions are to occur then both farm gate and social valuations indicate that these will be most readily derived from the sheep farm sector. In reality decision makers are likely to be faced with only limited resources to effect such conversions. In such situations our methodology is particularly suited to the identification of optimum sites for conversion onto which subsidies can be targeted. Figure 10.7 provides a useful illustrations of this capacity. Here we can target sites according to the net social benefits created by conversion.

Finally our results reveal an interesting dichotomy between economic analysis and policy practice. We have shown that the optimum location for conversions out of agriculture and into woodland is in highly populated, accessible, lowland areas. These combine high rates of tree growth with high recreational demand. However, it is only in recent years with the advent of the Community Woodland and similar schemes that policy has begun to recognise the strength of this argument[13]. The legacy of virtually all preceding policies has been a concentration of woodlands in upland areas, inaccessible to the majority of the population. Figure 10.9 illustrates this with respect to sub-compartments of Sitka spruce in Wales (superimposed upon an elevation map).

The overall message of our analysis is clear; extended economic analysis of both the internal and external net benefits of conversion shows considerable scope for bringing forestry down the hill.

[13]Interestingly it may well be a non-governmental organisation, the Woodland Trust, which plays a significant role in future forest development funded in part by a recent grant of over £6 million from the Millennium Fund (Smith, 1996).

Figure 10.9: Location of Forestry Commission sub-compartments of Sitka spruce in Wales (superimposed upon elevation)



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Chapter 11: Conclusions and Future Work

11.1: INTRODUCTION

This research draws upon a series of interrelated studies designed to provide an improved cost-benefit analysis of a proposed conversion of land use out of conventional agriculture and into woodland. The analysis covers a number of diverse questions and is necessarily complex. Consequently a number of conclusions can be drawn. To simplify this process, in the following section (11.2) we review the achievements of this research before, in the subsequent section (11.3), highlighting what we see as its principal attributes. Following this (section 11.4) we consider the shortcomings and problems of the study. This discussion leads us to the final section of the study (11.5) in which we discuss ongoing work and future extensions to this research.

11.2: SUMMARY OF RESEARCH ACHIEVEMENTS

The first phase of this research was concerned with monetary valuation of the recreational benefits of woodland. Given the open-access nature of this good, which produces no internal return to the landowner but is of significant social value, we were forced to rely upon non-market evaluation methods. Chapter 2 reviewed these methods highlighting the theoretical appropriateness of both the contingent valuation (CV) and travel cost (TC) techniques. The chapter also provided a theoretical analysis of the values elicited from these methods. This review process was extended in chapter 3 to an appraisal of UK applications of these methods to the evaluation of woodland recreation. This review raised a number of interesting issues, for example, studies failed to identify any significant link between recreational values and tree species. However, we highlighted a number of problems with prior studies both in terms of their methodology, data analysis and reporting. In an effort to identify values which could be transferred to woodlands in our study area, cross-study analyses of both TC and CV estimates were conducted. These yielded separate and significantly different valuation measures for subsequent consideration.

Concerns regarding prior studies were in part the motivation behind our own studies of recreation value presented in chapter 4. Here we investigated a number of study design issues, analysing the impact which differing methodology had upon resultant value estimates.

While our initial study was somewhat crude we feel that subsequent studies provide important parameterisation of design effects. More specifically we found that CV estimates varied significantly with issues such as question ordering, the inclusion or exclusion of questions regarding recreational budgets, choice of willingness to pay format, payment vehicle and respondent type. While much of this variation can be interpreted in line with economic theory this does raise the complex question of which value is the most appropriate for practical purposes. Our research into the TC method found that its valuations were also subject to variation according to the methodology employed. In particular we assessed the impacts of measurement effects, choice of unit values and estimation technique. Variation in estimates were found to be just as wide or even wider for the TC as for the CV approach. These findings considerably complicate the use of such evaluation methods. For the purposes of this study we have tried to define best practice rules for implementation of these methods.

Chapter 5 opens by considering the equally important question of how many people will visit a specified woodland site. The chapter also presents the first of a series of GIS-based models which dominate the latter part of the study. Here data from our field studies was used to estimate a visit demand function which, although theoretically simple, was methodologically sophisticated and proved reliable in predicting visits when assessed against a subsample of sites for which actual arrivals were known. Combining this with the various previously estimated transferable recreational visit values, we obtained a range of woodland recreation benefit values. These varied according to the valuation method used and methodological assumptions employed. From these we identified a preferred upper and lower bound estimate of recreation value for use in subsequent analyses.

The next three chapters switched the focus of analysis to consider tree growth and its related benefits. Throughout this we considered two species of tree, a representative conifer (Sitka spruce) and a typical broadleaf (beech). Chapter 6 assesses the costs and benefits of planting these species, producing estimates of net present value and its annuity equivalent. This necessitated a study of which discount rates might be appropriate for the various decisionmakers under consideration (farmers and policy makers). The chapter also provides market and shadow price assessments of these values to facilitate investigation of the value of woodland both to the farmer and to society. This dual assessment is repeated in all subsequent evaluations.

Chapter 7 presents the first GIS-based models of timber yield. Our methodology allowed us to use the Forestry Commission's sub-compartment database permitting a very substantial increase in sample size compared to previous studies. The GIS also allowed us to incorporate data on the environmental characteristics of a site taken from the Soil Survey and Land Research Centre's (SSLRC) LandIS database. The superior detail and extent of these data facilitated the estimation of yield models which were significantly more robust than those reported in the literature. Furthermore, information from chapter 6 allowed us to convert these yield estimates into maps of timber value for both our conifer and broadleaf species.

The yield model also provided the basis for our subsequent analysis of carbon sequestration in chapter 8. The latest Forestry Commission models on carbon storage in timber and liberation from its products were combined with information concerning soil carbon flux to produce assessments of the net impact of planting trees upon the carbon cycle. A review of the current literature on valuing carbon storage was used to provide a monetary evaluation of the results from this model which, as before, was prepared so as to produce analyses for both of our focus tree species.

Chapter 9 shifted attention from woodland to agriculture. The models presented here are unique on a number of criteria. First, they utilise farm level rather than Parish or other aggregated data. Secondly, they are the first GIS-based models of agricultural values. Thirdly, this methodology permitted the inclusion of the environmental characteristics of farms as explanatory variables in the value functions. A cluster analysis was used to identify homogenous sectors within the farm database. Separate analyses were conducted for the two principal sectors of sheep and milk production. Finally a shadow pricing exercise permitted modelling of social values as well as corresponding levels of farm gate income.

All the preceding analyses are synthesised in chapter 10 which provides a cost-benefit appraisal of converting the two farm types to either of the woodland types considered. Net benefits are calculated from both a farm gate and social perspective. Comparison of predicted values with the actual very low numbers of conversions led us to conclude that sheep farms were using a risk-weighted discount rate of about 6%. While this rate meant that the present level of woodland grants and subsidies made conversion unattractive from the farmers perspective, our analysis showed that conversion from sheep farming to conifer woodland generated substantial net social benefits and justified the relatively modest increase in grants and subsidies necessary to induce such conversion. The farm gate and social value of conversion from sheep to broadleaf woodland suffered from the long rotation lags of such species and produced lower values than conifers although some conversion was still justified. A particularly important finding was that the optimum location for conversion out of sheep farming was not, as under general planting practice, in remote upland areas but rather in heavily populated, high accessibility, lowland locations. However, when we turned to consider milk farms we found little economic justification for conversion to either conifer or broadleaf woodland.

11.3: PRINCIPAL ACHIEVEMENTS

As detailed in the previous section this research has achieved a number of objectives. However, we choose to emphasise two general points as its principal achievements; one methodological, the other empirical.

11.3.1: PRINCIPAL METHODOLOGICAL ACHIEVEMENT

The principal methodological achievement of this research is, we believe, the improved incorporation of spatial and environmental variables into a variety of economic models through the medium of GIS.[1] This brings much needed realism and the ability to model spatial complexity into a variety of economic analyses.

A number of examples of this methodology are presented here. The GIS is employed to incorporate the variable availability and quality of the road infrastructure and the distribution of population in our model of woodland recreation demand. The software is also used to manipulate and integrate environmental data into our analysis of agricultural values. Similarly, the GIS provides an ideal medium for integrating a variety of diverse data which had not previously been linked, such as the combination of SSLRC LandIS and Forestry Commission sub-compartment databases in our analysis of timber yields.

A further feature of this methodology is that the resultant maps provide readily clearly interpretable results which can readily be used by decisionmakers to analyse the impact of

[1]A number of studies have examined the potential for using GIS as a land use decisionmaking aid both in general (see, for example, Harrison et al., 1991; Norman et al., 1994; Hallett et al., 1996) and with specific reference to forestry (see, for example, Aspinall, 1991; Davidson, 1991; Blakeway-Smith et al., 1993). However, the present study is the first GIS based study to consider the multiple attributes of forestry within an economic appraisal.

policy changes and also provides information on the most appropriate sites for targeting policy initiatives.

The flexibility and analytic power of a GIS makes it, we feel, the ideal tool for incorporating and analysing the spatial complexity which is such an important part of the real world but is often so conspicuously absent from many economic analyses.

11.3.2: PRINCIPAL EMPIRICAL ACHIEVEMENT

This research presents a substantially more extensive and realistic cost-benefit analysis of the agriculture/forestry trade off than has been achieved in the UK to date. In particular we have significantly extended the appraisal of the external effects of such a conversion without recourse to wholesale simplifying assumptions.

The results of this analysis have important consequences for future policy. We have clearly demonstrated the potential for generating substantial net social benefits by converting some sheep farms into woodland. Furthermore, the identification of optimum conversion sites, facilitated by the methodological advances discussed above, indicates that planting policy to date has been diametrically opposed to that which is required to maximise economic benefits. However, our analysis has also shown that existing levels of woodland grant and subsidy are insufficient to induce conversion (a result which reflects real world observations). Nevertheless, our results indicate that only modest increases in these grants and subsidies would be necessary to induce substantial rates of conversion and generate significant net social benefits.

In essence our analysis has highlighted the marked difference between the market appraisal of the status quo and its social value. By including externalities in our analysis we show that the present situation is one of poorly targeted government intervention leading to market failure, a situation which can readily be remedied by linking transfer payments to the total economic value of goods rather than to their market price.

11.4: SHORTCOMINGS AND PROBLEMS OF THE RESEARCH

This was a relatively ambitious project covering a wide range of analyses some of which have scope for improvement. One such area is the need for further consideration of the impact of statistical error in a multi model system. In particular while actual versus predicted tests were conducted on recreational demand and timber yield estimates, to date such a checking analysis has not been extended to our agricultural models.

A number of issues arise from our analysis of recreation values. One point, which is more of a finding than a criticism, is that our CV and TC studies have raised significant concerns regarding the impact of study design, implementation and data analysis upon resultant valuation estimates. While this is an interesting research finding it does raise questions regarding the use of such values in our subsequent cost-benefit analysis. We have attempted to address these by using upper and lower bound estimates in this analysis but feel that this is a less than ideal solution. In summary more research into the understanding and control of design effects is called for.

Another valuation issue echoes our earlier concern about the need to compare estimates with actual on-site measures. While we were able to perform a small sample check on our estimates of visitor numbers, limited resources meant that we were unable to verify the appropriateness of our transferable recreation values through on-site surveys.

A final issue that we would choose to highlight is that, while our study attempts to significantly extend the analysis of all the costs and benefits, we have omitted certain items (see figure 1.2). Of these the more major omissions include sporting revenues (which in some locations may be highly significant; see McGilvray and Perman, 1991), livestock shelter, and externalities such as biodiversity and habitat value (Jenkins, 1984, 1986; Good, 1987; Good *et al.*, 1991; Peterken, 1993), acidification impacts[2] and landscape amenity effects (Dillman and Bergstrom, 1991; Campbell and Fairley, 1991; Lavers and Haines-Young, 1991). Plans to address these and other concerns are detailed in the following section.

11.5: RECENT, ONGOING AND PROPOSED EXTENSIONS

Many of the concerns raised above are already the subject of ongoing research. The improvement of methods for the monetary evaluation of environmental preferences is a major focus of this work and a number of initiatives are ongoing. Work on the CV method includes the investigation of the theoretical basis of preference construction. Here we have found the

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[2]Both in terms of the effect of acid rain upon tree growth (EC-UN/ECE, 1994) and the impact of afforestation upon water quantity and quality (Hornung and Adamson, 1991).

CV method to be of immense help in testing the principles of economic theory. Through a series of real and hypothetical market experiments[3], the CV technique has been used to test phenomena such as reference dependent utility theory (Bateman *et al.*, 1995a; forthcoming a and b) and part-whole effects (Bateman *et al.*, 1996a/b and forthcoming c), while ongoing research investigates the role and incorporation of risk perceptions into models of economic valuation[4]. Further work has included the compilation and editing of a volume of CV papers from internationally renowned commentators (Bateman and Willis, forthcoming), an analysis of the potential for using CV to estimate non-user values (Bateman *et al.*, 1995b; Bateman and Langford, forthcoming), applications to previously unstudied resources (Lake *et al.*, 1996) and improvements to the statistical analysis of CV data (Langford *et al.*, 1996a and b; Langford and Bateman, forthcoming; Bateman *et al.*, forthcoming d).

Our GIS-based methodology is also facilitating ongoing investigation of the travel cost (TC) method. We have recently completed a further analysis of measurement effects in TC studies (Bateman *et al.*, 1996c) and show that the variation in resultant surplus measures can significantly exceed that of the often-criticised CV method (Bateman *et al.*, 1996d). The implication of this work is that the status accorded to revealed as opposed to expressed preference valuation estimates is often spurious. However, we feel that the use of GIS allows the researcher to directly address these issues and facilitates a very substantial improvement in the execution of TC studies which may then justify such status.

With the help of awards from English Nature and further funding from the ESRC[5] we have also made significant recent progress in extending and improving our benefit transfer model (Bateman *et al.*, 1996d/e/f/g; Brainard *et al.*, 1996). This now incorporates not only the price variables used in this research but also the socio-economic status of visitors and the availability of substitutes (a complex spatial variable for which GIS is the ideal analytical tool). Ongoing work in this area focusses upon further refinement of this model and the use of the resultant transferable demand function as a direct source of valuations thereby obviating the need to resort to separate meta-analysis estimates which lack the context sensitivity of our

[3]Funded by the ESRC (grant no. W119-25-1014). Awarded to the author in collaboration with Professor Robert Sugden, Dr Alistair Munro, Dr Chris Starmer and Professor R. Kerry Turner (all UEA).

[4]Various projects funded by the ESRC and Environment Agency (including: grant no. L320223014; its recent extension; a 3 year project awarded under the ESRC's Risk and Society Programme; and two CASE studentships). Co-researchers on these projects include Professor Robert Sugden, Professor R. Kerry Turner and Dr Ian Langford.

[5]Awarded to the author in collaboration with Dr Andrew Lovett (ESRC grant no. L320223002).

benefit transfer model.

As noted above, our analysis of the externalities of woodland is incomplete. One area of ongoing work is the assessment of landscape amenity. Further support from the ESRC[6] and the Commission of the European Community[7] has allowed us to develop ideas we put forward in various papers (Bateman, 1993; Bateman, 1994; Bateman and Bryan, 1994)[8] regarding a GIS-based hedonic pricing (HP) model of such values. The viewshed calculation capabilities of a GIS make it the ideal tool for compiling mass databases of an area thus obviating the need to rely on the crude distance-based measures typical of most HP models of landscape amenity. This work is now well advanced and seems very promising.

A further area of ongoing research examines the biodiversity and habitat values of woodland and the implications for these values of implementing the optimal policy changes implied by the present study. This work combines our various datasets with those from the British Trust for Ornithology (BTO) to use certain bird species as flags for the wider biodiversity implications of policy change.[9] This research is still under development but early indications and the GIS literature[10] suggest that this will provide a powerful tool for identifying the wider effects of the decision regarding which tree species to use in conversion schemes (with broadleafs seeming significantly superior in this respect).

One area in which we have to date achieved nothing more than a review of the literature (Bateman, 1992), is in the incorporation of the acidification effects of woodlands, particularly those composed of conifers. Here, while some evidence is mixed, the general consensus is that conifers can cause acidification damage to watersheds. There is considerable scope for addressing this issue. First, the literature is extensive, particularly with reference to Wales (see, for example, the numerous papers contained in Edwards *et al.*, 1990). Secondly a number of previous studies have shown that GIS provides the ideal tool for

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[6]In the form of a studentship.

[7]Awarded to the author. This research relies upon data and software kindly loaned by the Ordnance Survey; the Transport Research Laboratory; the University of Glasgow (CHRUS); the University of Paisley; and Strathclyde Council to whom we are very grateful.

[8]Relevant background material is presented in Campbell and Fairley (1991), Dillman and Bergstrom (1991) and Lavers and Haines-Young (1993).

[9]This research is a collaboration between UEA (Dr Paul Dolman, Dr Andrew Lovett and the author), the SSLRC and the BTO. An application for research funding is currently under consideration by the Natural Environment Research Council (NERC).

[10]See, for example, the GIS-based woodland habitat study by Gurnell *et al.* (1996). GIS has also been used to assess the potential for using woodlands as a bio-fuel source (Scholes, 1996; see also CAS, 1989).

catchment analysis[11] (Adams *et al.*, 1995). This should make the future analysis of acidification impacts reasonably tractable.

While we recognise that the research presented in this thesis is not fully comprehensive with respect to the full complexities of land use change we do believe that it represents a significant improvement upon the current state of decision analysis. Furthermore we feel that the methodology developed here is readily amenable to extension and that future research may progress this into a practical decision support system of considerable assistance to policy and decision makers as well as being of interest to academics and users of the land alike.

THE END

[11]Such research would also allow consideration of related issues such as the impact of afforestation upon hydroelectrical potential (see Barrow *et al.*, 1986).

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